V. VLADIMIROV

dies, moulds AND jigs

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Section I

WORKPLACE LAYOUT. TOOLS AND SPECIAL-PURPOSE EQUIPMENT. MATERIALS

Chapter 1

Workplace and Tools for Hand Operations

1.1. Layout of a Fitter's Workplace

Manufacturing jigs and fixtures involves various intricate operations. The most frequently used operations are the following: marking work, taking precision measurements, jig boring, reaming and thread cutting, cutting out recesses, filing surfaces and holes, scraping, trimming and polishing with hand-held power-driven tools, simple heat treatment of tools and workpieces (annealing, hardening and tempering), lapping and finishing hardened workpieces, polishing machined surfaces.

A high-skilled fitter engaged in making and repairing dies, jigs and fixtures is also expected to operate some machine tools usually to be found in tool shops, such as drilling, filing, tool-grinding, surface-grinding, lapping, polishing, and some other machines. He will also be able to make use of tools intended for precision marking and measuring work.

A fitter must of necessity make some special-purpose tools, jigs and fixtures to be used in his work, for instance, scrapers for work on shaped surfaces, bent-type files and needle files, gravers, caulking chisels, lapping tools, etc. A fitter is to take special care of his workplace layout if he wants to enjoy efficient work.

A section of a shop or a workshop allotted to a workman or a team and fitted out with the equipment, accessories, tools and materials necessary for performing a certain production task is called a *workplace.*

The workplace of a fitter for making dies, moulds, jigs and fixtures (Fig. 1) is provided with a bench on which the workpieces are handled, surface plate for assembling, dismantling, testing and adjusting operations, as well as with a marking-off plate.

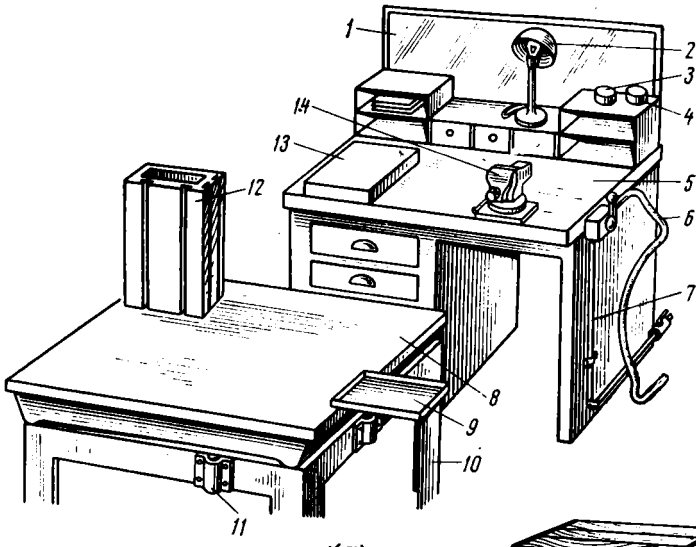
The bench should be connected to a 36-volt a.c. power supply source used for illuminating the workplace and a H.F. supply line (200 hertz) for ellectrically driven tools; it should be fed with compressed air for operating air-driven tools, scavenging workpieces, and testing ready products. A single-fitter work bench (Fig. 1*a*) is of about 1400 × 800 millimetres in size. The height of the bench with the surface plate on it should suit the fitter's height. It is good to cover the surface of the bench with linoleum (steel sheets should be avoided). Drawers for keeping tools are arranged beneath the top on the left-hand side of the bench while the space on the right-hand side beneath the vice is left free for the fitter's feet. Placed near the bench is a stable stool adjustable to benchman's height.

The bench is provided with a swivel parallel vice having a hand screw clamp. Air-operated vices are not suitable for fitters making dies, moulds, jigs and fixtures since they do not allow the operator to feel and adjust the clamping strength, which is necessary in dealing with precision and intricately shaped workpieces.

The benchman should have at convenient reach a set of frequently used tools and accessories not to waste time looking for them. To find the required tools quickly, the bench is provided with drawers fitted with detachable trays having specially shaped receïvers for tools.

Fig. 1. Equipment of workplace

(*a*) work bench and surface plate; (*b*) marking-off plate; (*c*) three-shelf support; (*d*) height-adjustable wheeled support; *1*—guard screen; *2*—bench lamp; *3*—workplace illuminator receptacle; *4*—H.F. current receptacle for electrical tools; *5*—working section of the bench; *6*—rubber hose; *7*—compressed air supply line; *8*—surface plate; *9*—movable tool shelf; *10*—surface plate pedestal; *11*—shelf bracket; *12*—turn-over mounting V-block; *13*—master plate; *14*—parallel vice; *15*—round plate; *16*—dividing head; *17*—box; *18*—hollow cylinder; *19*—clamping device; *20*—marking-off V-block; *21*, *22*—height gauge with centre finder; *23*—scriber; *24*—supporting V-blocks; *25*—supporting pieces; *26*—shelf; *27*—jack; *28*—screw clamp; *29*—base; *30*—cabinet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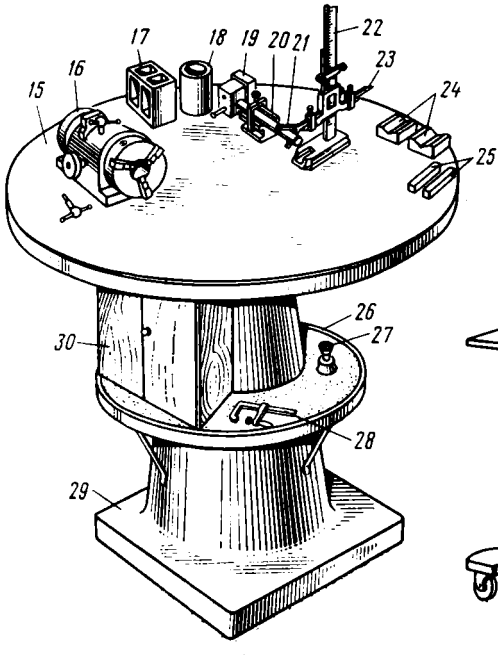
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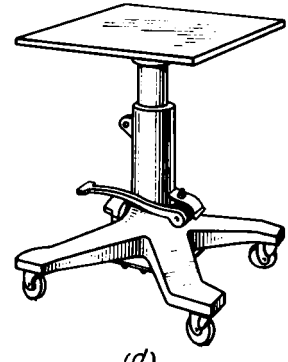

(d)

The surface plate should be used only for operations requiring high accuracy. Avoid using this plate for work involving blows, never put working tools upon it lest its surface be scratched.

The measuring tools are kept in a specially allotted drawer of the bench, each tool having its own nest.

Arranged near the bench is a rectangular or round (the latter being preferable) marking-off plate for marking workpieces. Round plate *15* made of cast iron is shown in Fig. 1*b*. The plate is put on base *29* accommodating shelf *26* and cabinet *30* for storing measuring tools and accessories. The operator usually keeps on the plate dividing head *16*, box *17*, hollow cylinder *18*, clamping device *19*, marking-off V-block *20*, height gauge *22* with centre finder *21* and scriber *23*, supporting V-blocks *24*, ground supporting pieces *25*, jack *27*, and screw clamp *28*.

The workpieces should be so arranged on the workplace that they are within easy reach of the benchman. For this purpose use is made of different stationary and moving supports and tables. The stationary supports are in most cases of a multishelf type. Their design and size are selected to suit the dimensions of jigs and fixtures to be manufactured. Fig. 1*c* shows a typical stationary three-shelf support. The upper shelf is made smaller than the two lower ones, which allows the workman to use conveniently the second shelf and to see well the things on it.

When performing assembling operations (especially when handling large-size workpieces) movable height-adjustable supports (Fig. 1*d*), which can be placed conveniently where required, are used.

To keep fasteners and small-size parts of the future units, a portable case with a grate bottom proves good since no filings, chips or wastes will accumulate in such a case.

Each tool should be given a permanent place in a case or on the bench top so as to save the benchman's time spent on looking for what he needs. Precision measuring tools should be kept in special casings. The tools for work on hardened workpieces should be kept separately from those used for dealing with non-hardened workpieces. Nor should the workpieces be kept together with finished articles.

Adequate illumination of the workplace cannot be over-

estimated. The light should be bright enough and fall on the workpiece and not in the benchman's eyes. The best illumination will be achieved by providing dispersed light which creates no highlights interfering with work. The operations to be performed, however, may call for use of a portable lamp with a hinged lamp shade.

To determine a light clearance between the workpiece and the measuring tool or that between two parts (for instance, between the die and the punch) a sight lantern with white dimmer is used; such a lantern is sometimes mounted right on the bench top.

1.2. Special-Purpose Chipping Tools

In manufacturing jigs and fixtures a benchman makes use of a great variety of tools. Some of them are ordinary benchman's tools, others are special tools intended for one particular type of workpieces.

In making dies and moulds a wide use is made of chisels of different shapes and sizes, as well as of special shaped cape chisels. Figure 2 shows the most popular chipping tools

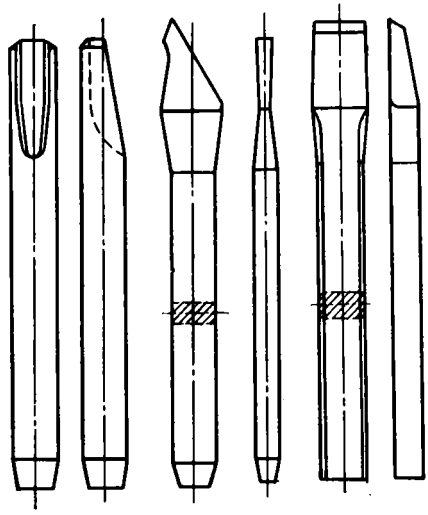

Fig. 2. Shaped chipping tools

applied when much stock is to be removed from intricate surfaces which defy machining. When using shaped chisels and cape chisels pneumatic hammers will be found very efficient for chipping cast pieces. Such hammers allow continuous chipping operation throughout a cut while uniform chipping results in better surface as compared to that obtained when using an ordinary machinist's hammer.

1.3. Special-Purpose Filing Tools

When making the components of dies, jigs and fixtures in modern tool shops fitters have no longer to remove much stock by hand since they receive the workpieces which have been either finish-machined or given but moderate allowances for final finish.

Filing can be applied to concave and convex surfaces, shaped holes, various cavities and depressions, when fitting the mating components, chamfering and burring. All these operations can be performed by *ordinary files* of the required shape having medium or fine cuts.

Needle files should be used for filing small surfaces, in narrow places or in small holes which cannot be filed by ordinary files.

For work in difficult-of-access places of some parts (for instance, for trimming the grooves of dies and moulds) *special-purpose files* shown in Fig. 3*a* are used. These are made from fragments of ordinary files or needle files soldered up to a cold-rolled steel rod. The rod is driven upon the handle and bent so as to allow convenient trimming inside the die or mould.

For more efficient job in the tool shops the filing and trimming operations can be performed on filing machines (see Para 2.6). The *machine files* on filing machines are of special design, they differ in cross section and cut spacing.

A feature of machine files is the uniform cross section over their entire working portion. The machine files come in two types: type I without a rest centre, type II with a rest centre (Fig. 3*b*).

Type I files have no cut on the ends. The files are secured with their plain ends in movable frames of a filing machine. Type II files are made with one shank. The other end of

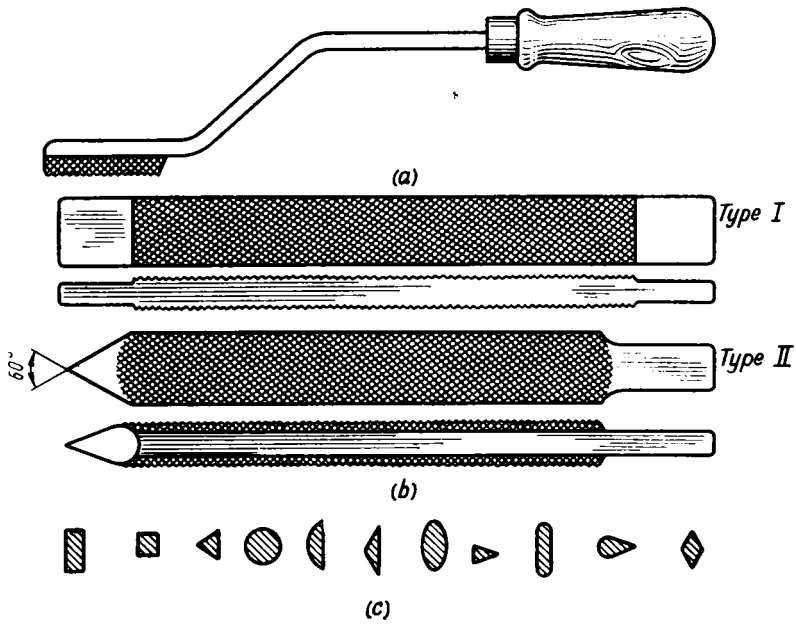

Fig. 3. Filing tools
(*a*) bent file with an extension made from a fragment of ordinary or needle file; (*b*) machine files; (*c*) cross section of power files

the file is made as a rest centre with an angle of 60°. The length of type I files is 100, 125, 150, and 200 millimetres, that of type II files 150, 200, and 250 millimetres.

The cross section of type I files is from 2 × 1 to 10 × 5 millimetres, that of type II from 12 × 3 to 26 × 9 millimetres. The machine files have a double cut with inclination angles of the main cut of 25° or 35° with respect to the axis of the file. The number of cuts over 10-millimetre length is from 11 to 40 depending on the size and purpose of the file.

1.4. Rotary Files and Burrs

Rotary tools, powered by air-driven or electric motors, are very efficient for machining shaped surfaces of die and mould parts.

Non-hardened parts are machined with rotary files and burrs; hardened parts, by abrasive rotary heads.

Figure 4 shows *rotary burrs* which come in one of two types: one-piece and attachable. One-piece rotary burrs (Fig. 4*a*) are made of high-speed steel. Their shank and working portion are made as one piece. The maximum diameter of the burr working portion is 16 millimetres, the minimum diameter being 3 millimetres; the shank diameter is 6 millimetres irrespective of the tool size.

Attachable rotary burrs (Fig. 4*b*) are made hollow and screwed on the arbor of structural steel. They have no shank, their working portion being made of high-speed steel. The maximum diameter of attachable rotary burrs is 32 millimetres, the minimum being 12 millimetres. The holes of these tools are threaded from M10 to M5, depending on the outside diameter.

Rotary files, similar to one-piece burrs in shape (Fig. 4*c*), are used for trimming operations on workpieces previously machined with burrs or on machine tools. They are made of high-speed steel, carbon tool steel, and cemented carbides.

The speeds and feeds at which rotary files are most efficient depend upon the material to be cut and the file material. When filing steel parts, for the files made of carbon tool steel and high-speed steel the following speeds are recommended:

File dia, mm . . .	up to 3	3-5	6-10	11-14	15-16	17-20	21-25
File speed, rpm . . .	4 600	3500	2800	2300	2000	1900	1700

The speeds for cemented carbide files can be increased 3-5 times against those for conventional tools.

The speeds for burrs are 1.5-2 times lower than those for files of respective diameters.

Abrasive rotary heads (Fig. 4*d*) are set on a steel rod (arbor) and secured with a synthetic glue or low-melting alloy. The rotary heads operate in the same way as rotary burrs and files but they are given speeds two or three times as high as the files.

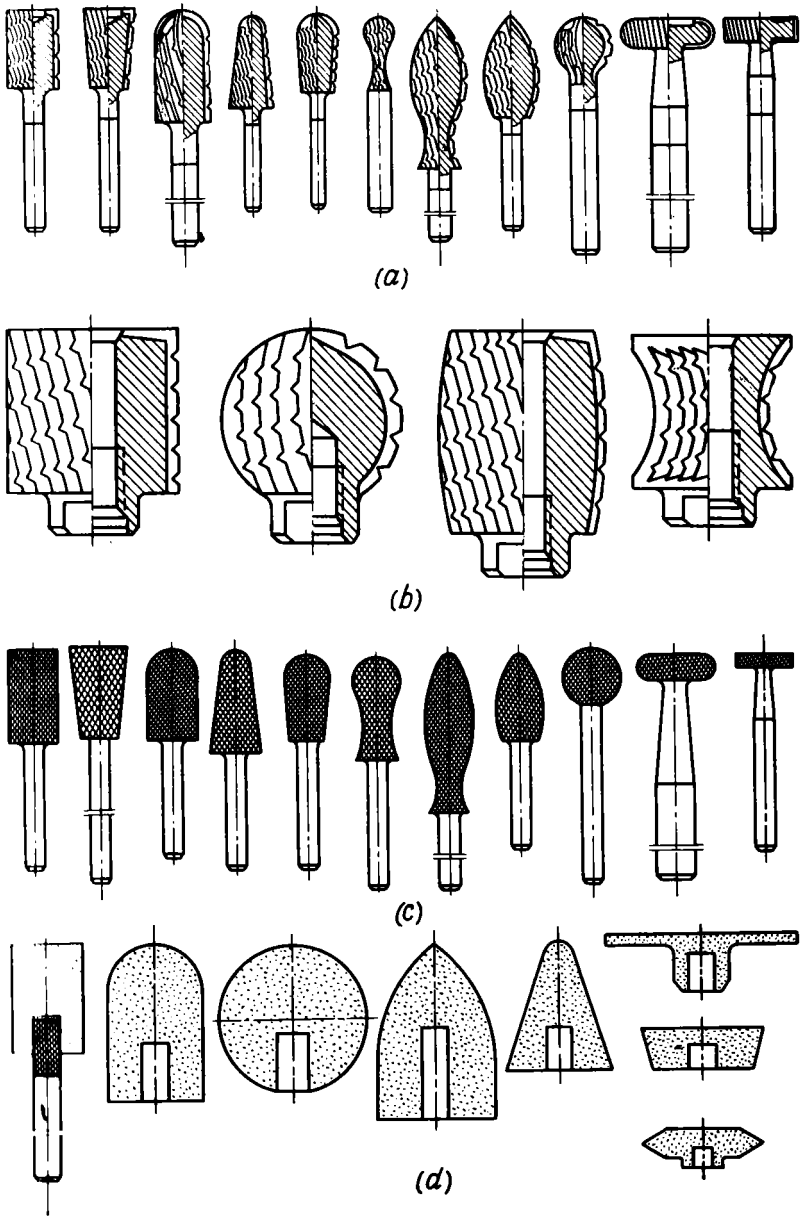

Fig. 4. Rotary files and burrs

(*a*) one-piece rotary burrs; (*b*) attachable rotary burrs; (*c*) rotary files; (*d*) abrasive rotary heads

1.5. Diamond Tools

Modern tool-making practice calls for a wide application of different tools made from natural and synthetic diamonds. High expenses on diamond tools are well paid back by increased efficiency of labour and high-quality machining obtained with such tools.

In manufacture of dies, jigs and fixtures, diamonds and diamond tools are used for finish machining of hardened die and mould parts as well as for polishing and lapping cemented carbide inserts for them.

Diamond tools come in various types, the most popular of them being diamond wheels, heads, whetstones, needle files, and laps.

Diamond wheels (Fig. 5*a*) are made of aluminium alloys or plastics with a diamond-bearing coating consisting of diamond powder, bond, and filler. The wheels can be made with metal and organic bonds.

The metal-bonded wheels (an alloy of copper and tin with silver additives) can be used for grinding the workpieces of hard alloys, hardened steel, cast iron provided they are duly cooled and timely trued. Such wheels are good for rough machining when much stock is to be removed (up to 0.5 millimetre) and a surface finish of Class 8 or 9 obtained.

The organic-bonded diamond wheels (bakelite, natural rubber, shellac, and other resins) are used for final finish with an allowance of not more than 0.05 millimetre and a surface finish of Class 10-12. Such wheels do not practically get soiled and require no coolants but the consumption of diamond as calculated per one weight unit of removed stock is 2.5-3 times more as compared to grinding by metal-bonded wheels. The shape and size of diamond wheels are selected to suit the shape of a workpiece.

The diamond wheels are available in diameters of 50 to 250 millimetres with the thickness of a diamond-bearing coating from 1.5 to 6 millimetres.

One of the most important features of the diamond wheel is the degree of diamond concentration in the diamond-bearing coating, i.e., the amount (in milligrams) of diamond grains per one cubic millimetre of the diamond-bearing

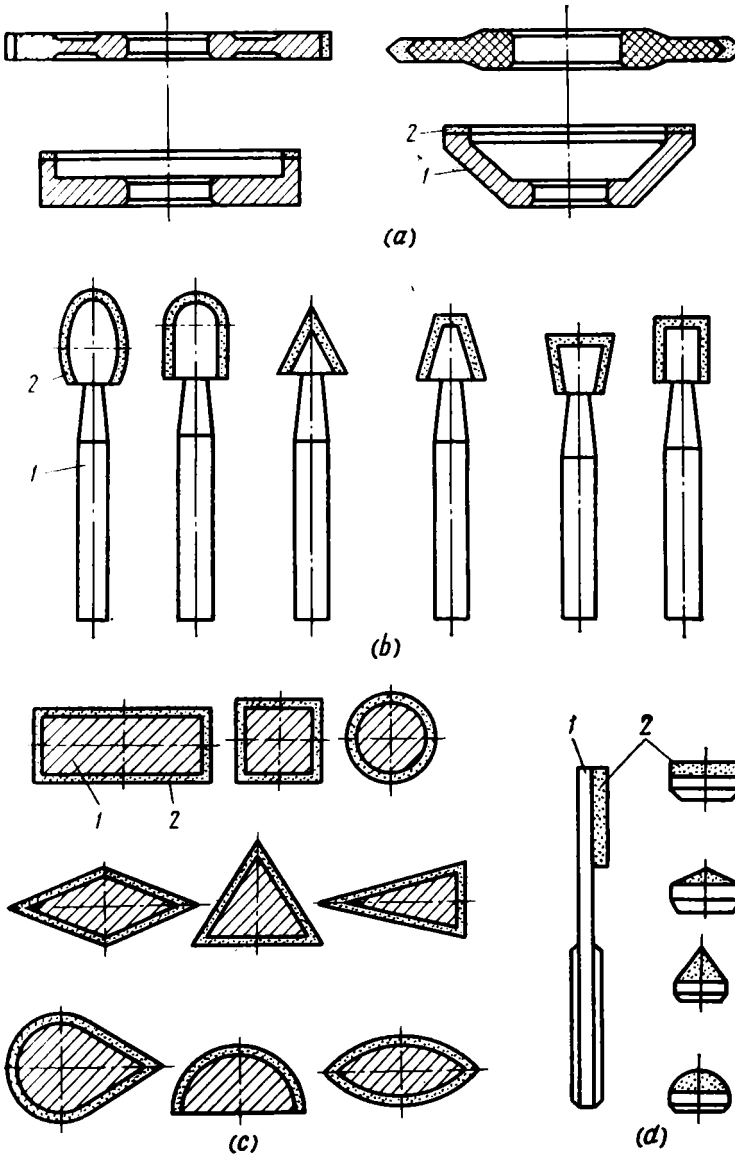

Fig. 5. Diamond tools

(*a*) diamond wheels; (*b*) heads; (*c*) needle files (cross section); (*d*) laps; *1*—metal body; *2*—diamond-bearing coating

coating. The concentration is considered 100 per cent with 0.878 milligram of diamond grains per one cubic millimetre. The diamond wheels are available with 25, 50, and 100 per cent concentration. With 100 per cent concentration the diamond grains cover 25 per cent of the diamond-bearing coating.

The diamond tools used for hand lapping are of low diamond concentration (25 per cent).

Diamond heads (Fig. 5*b*) are similar to abrasive heads in shape. They are made with metal or organic bonds. The grain size of diamond heads is similar to that of diamond wheels. The diamond heads are used in pneumatic miniature air grinders and electrical flexible-shaft machines with spindle speed from 5000 to 15,000 rpm.

The heads comprise a steel rod and a diamond-bearing layer which is applied to the rod by pressing or galvanizing. The bonds for the heads are the same as used for diamond wheels. The heads can be from 2 to 22 millimetres in outside diameter, the thickness of the diamond-bearing layer being up to 1 millimetre.

Diamond whetstones are made mainly of synthetic diamond powders with metal or organic bonds. The diamond-bearing layer is applied to a steel arbor which can be of flat, three-edged or convex shape. The arbor length is 120 millimetres. The width of the diamond-bearing layer can be from 6 to 10 millimetres with the length of 40 millimetres.

The methods applied for work with diamond whetstones do not differ from those using ordinary abrasive whetstones. When the organic-bonded whetstones get soiled they should be cleaned with pumice stone, the metal-bonded ones should be trued with a flat abrasive whetstone of green silicon carbide of grain size 40-25 and of medium hardness.

Diamond needle files are made of steel whose surface is coated with the diamond powder grains by galvanizing. The standardized sections of diamond needle files are shown in Fig. 5*c*. The needle files of all sections are blunt ended. A set of needle files allows filing on intricately-shaped surfaces of hardest materials, such as steels with hardness number of R_C 64 and hard alloys.

Diamond laps (Fig. 5*d*) resemble fitter's files in shape.

They are just steel rods of a rectangular, radiused or angular cross section to whose surface diamond-bearing coatings of different grain sizes are applied.

The lapping operation with the diamond laps can be performed either by hand or with the aid of hand-held air-operated heads, or else on the lapping-and-honing machines where the working tools are imparted straight reciprocation.

The industry has come to employing pieces of a special wire coated with diamond powder for cutting out (filing) the contour of the workpiece in the die made of hardened steel or hard alloy.

1.6. Polishing Buffs

Types of buffs. Polishing is done with soft elastic buffs with fine abrasive grains glued on them or impregnated with polishing pastes rubbed therein. The polishing buffs can be made of felt, rough felt or different kinds of cloth. When polishing rather large surfaces (over 1 square decimetre), usual practice is to use cloth wheels made of cotton fabrics which are arranged in layers, hand-sewn, and glued together. The cloth buffs can be of full-disc, pieced, spoke, and packed types.

Full-disc buffs can be easily set up on the spindle of a polishing machine, they are well balanced and do not run out too much. Such buffs ensure high-quality polishing, when necessary mirror-like surface is required.

Pieced buffs and *spoke buffs* are more convenient for polishing operation since they allow the workpieces of different sizes and shapes to be treated with the resulting high-quality polishing.

The advantages of the spoke buffs (Fig. 6*a*) as compared to ordinary full-disc buffs consist in their uniform wear and good cooling of the surface of both the workpiece and the buff; besides they provide better adherence of abrasive material in the folds.

Packed buffs (Fig. 6*b*) are ventilated well when they revolve in the direction opposite to the folds and retain securely the polishing pastes. With a change in the direction

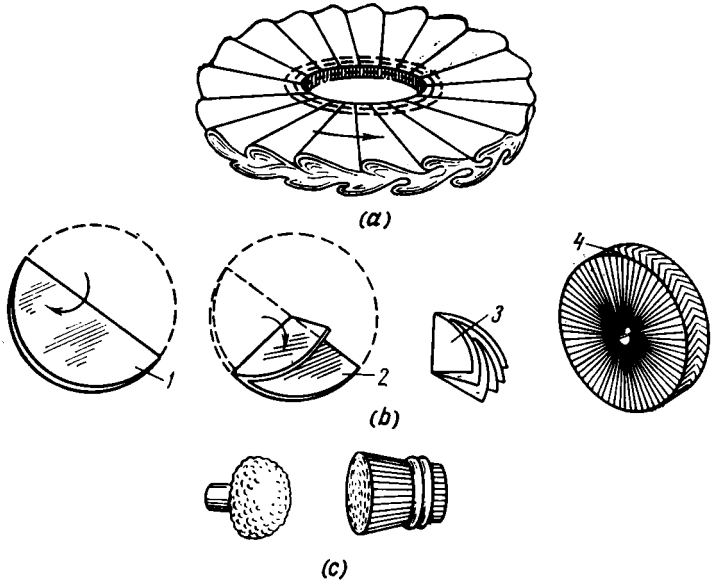

Fig. 6. Polishing buffs
(*a*) spoke buff; (*b*) packed buff; (*c*) polishing heads; *1*—double-folded disc; *2*—four-folded disc; *3*—packed segment; *4*—ready buff

of revolutions the segments become very elastic. This allows the same buff to be used for different polishing work.

For polishing the intricately-shaped moulds having recesses, it is good to use *polishing heads* (Fig. 6*c*) made of rough felt, felt or cotton wool.

The felt polishing buffs and heads provide for the best polishing finish, high efficiency, and economical consumption of polishing materials since they retain the abrasive paste well.

Attachment of buffs. Small-diameter felt buffs are mounted on cylindrical arbors provided with the flanges to clamp the buff and with the shank which is fixed in the chuck of the grinding-and-polishing hand machines. The polishing buffs 30 to 55 millimetres in width (cloth and felt) are usually secured directly on the taper-threaded spindle of the polishing machine. To mount or replace a polishing buff

without delays, a special tip is used which is provided with a fixed and balanced buff screwed on the polishing machine spindle with parallel thread. The buffs wider than 55 millimetres are secured on the spindle by the flanges tightened with a nut. This is a most reliable method of securing wide buffs.

Extensive surfaces are polished with the aid of double-ended machines, similar to emery grindstones, with the drive inside the bed. The machine spindle speed can be varied from 1300 to 3000 rpm by changing the belts on stepped pulleys. The speed is selected to suit the diameter of the buff and the polishing requirements (the smaller the buff diameter, the higher the speed). Finish polishing is done with a higher peripheral speed of the buff. The buffs less than 200 millimetres in diameter are given the speed of 3000 rpm, those of 300 to 350 millimetres in diameter operate at a speed of 2000 to 2400 rpm.

Chapter 2

Power Tools and Special-Purpose Equipment

2.1. General

Hand-held power tools are such tools whose main working motions are performed with the aid of the respective motor while auxiliary motions as well as control of the tool are executed by hand. The purpose of such tools is to make work easier and more efficient when drilling, reaming, threading, cutting, riveting, and performing other manual operations.

The power tools used in the manufacture of dies, jigs and fixtures are driven either by electrical power or compressed air. As to the mode of the motion of their working parts, the power tools, no matter what motor is used, are classified into those with rotation and reciprocation. The power tools are expected to be light in weight, small in size, compact, handy, and safe in operation and maintenance. They are to operate reliably and provide high-quality work.

The power tools driven by compressed air are safer than electric-operated tools although the low-voltage electric tools can be considered safe enough unless they are used in explosion-hazardous conditions. The ordinary electric-operated tools should never be used in explosion-hazardous conditions.

The hand-held electric tools operated at factories are usually supplied from the single-phase low-voltage mains (36 volts) of the standard industrial frequency (50 hertz). Large-size tools of power exceeding 200 watts and over 2 kilograms in mass are fed from the standard three-phase 220-volt, 50-hertz a.c. mains. There are also electric tools fed from the special three-phase mains of a higher frequency (200 hertz) under a voltage of 36 and 65 volts.

Pneumatic tools are connected to the compressed-air lines with a pressure of 6 atmospheres. The pneumatic tools with rotation employ vane-type motors of one-sided or reverse rotation.

2.2. Cutting and Chipping Tools

Tool steels used for the manufacture of dies, jigs and fixtures are of high hardness. Cutting and chipping steel blanks by hand is labour-consuming and calls for much effort. To facilitate fitter's work, different power tools are employed. The most popular power tools for cutting and chipping are air-operated hacksaws, electric shears, pneumatic hammers.

Air-operated hacksaws (Fig. 7*a*) are driven by compressed air with the aid of a vane-type motor. To allow the operator to see the severing process better, the used-up air is fed to the cut and blows off the chips. The hacksaw is provided with changeable clamps to secure the blades of different size.

Electric shears (Fig. 7*b*) are intended for severing and cutting out shaped blanks from metal sheets not thicker than 2 millimetres. The design of the shears is as follows. The rotation of the shaft of armature *1* in the motor is transmitted to eccentric shaft *2* through the gearing. The rotation of the shaft is transformed into the reciprocation of slide *3* for which purpose the eccentric pin of the shaft

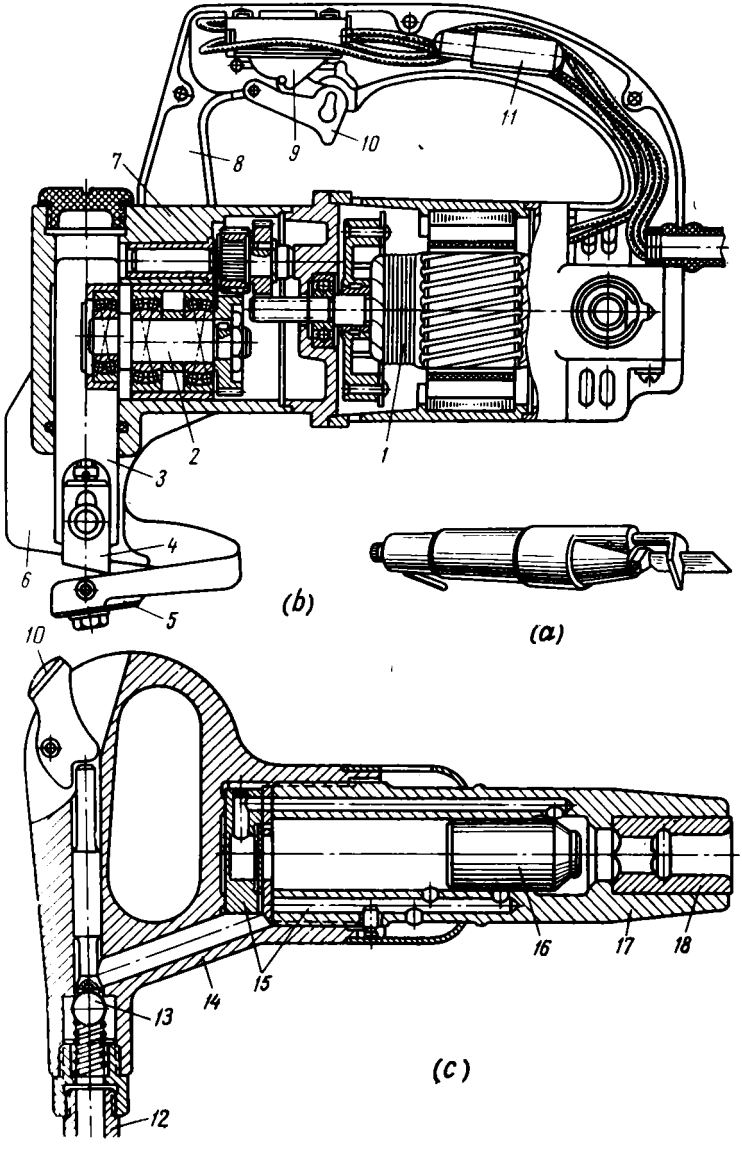

Fig. 7. Power tools for cutting and chipping metal

(a) air operated hacksaw; (b) electric shears; (c) pneumatic hammer; *1*—armature; *2*—shaft; *3*—slide; *4*, *5*—movable and fixed blades; *6*—steel plate; *7*—reducer; *8*—handle; *9*—switch; *10*—trigger; *11*—capacitor; *12*—compressed-air hose; *13*—oil valve; *14*—hammer body; *15*—air-distributing system; *16*—steel head; *17*—hammer trunk; *18*—tool casing

enters the cross slot in the slide. Movable blade *4* is attached to the slide. Serving as a rest for fixed blade *5* is steel plate *6* screwed to the aluminium body of reducer *7*. To provide for the required clearance between the blades, the fixed blade is adjusted in the plane perpendicular to the plane of the cut. Handle *8* accommodates switch *9* actuated by pressing upon trigger *10*. To eliminate radio interference, the electric circuit of the shears has capacitor *11* which is also in the handle.

A pneumatic hammer shown in Fig. 7*c* is used for chipping grooves and cavities in the components of dies and moulds by means of a chisel, for chipping off edges, chipping out faulty spots in castings and forgings, for caulking punches in their retainers, as well as for riveting.

2.3. Drilling Tools

For drilling and counter-sinking holes up to 9 millimetres in diameter in difficult-of-access places, hand-held electric drills weighing not more than 2 kilograms are used as bench drilling units.

Electric drills for making small holes (up to 3 millimetres in diameter) are sometimes made so that the motor body is in the tool handle. The electric drill consists of an electric motor, gearing, spindle, and starter.

Figure 8*a* shows a small-size electric drill of a gun-type, intended for drilling holes up to 6 millimetres in diameter. The spindle runs at 3000 rpm, the overall size of the drill is 220 × 70 × 130 millimetres, the mass without the chuck and cable is 1.6 kilograms. The electric drill is supplied from the three-phase a.c. mains of 36 volts and 200 hertz, consumed power being 120 watts. The electric drill comprises casing *1*, electric motor *2*, partition *3*, reducer body *4*, and spindle *5*. The rotor of the electric motor runs in two ball bearings, one of them mounted in casing *1*, the other in partition *3*. The rotor shaft carries impeller *6* which cools the operating electric motor. When trigger *7* is pressed on, the contacts of the switch close up, lock *8* is actuated by the spring and enters the hole of the trigger plate to hold the trigger in the ON position. For switching off the electric motor press on the lock.

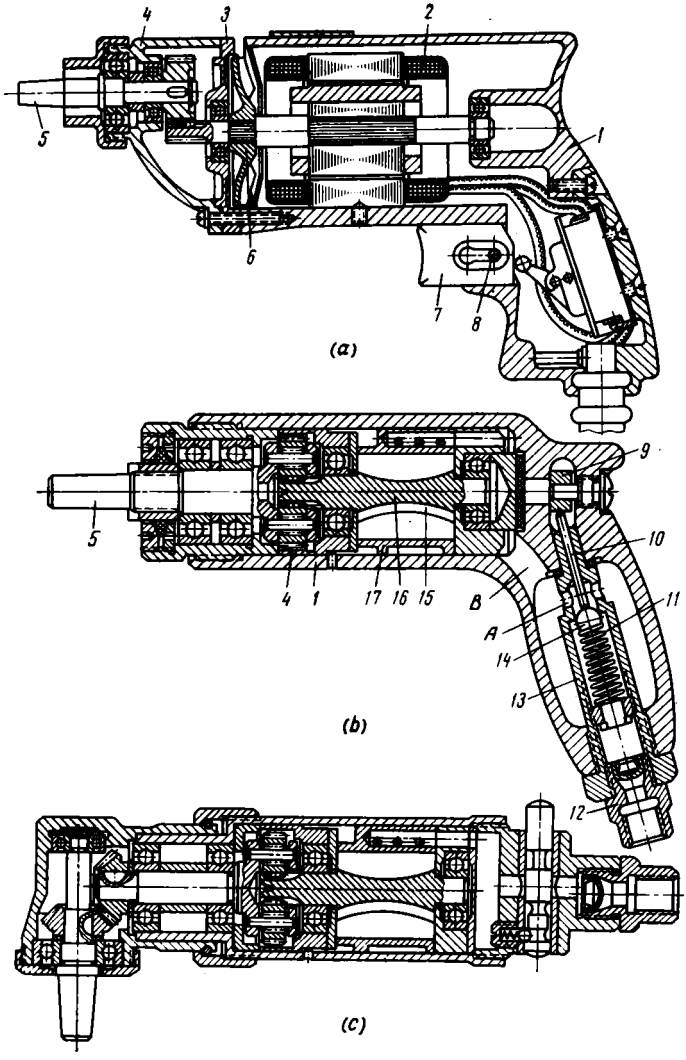

Fig. 8. Small-size drilling tools

(*a*) gun-type electric drill; (*b*) gun-type pneumatic drill; (*c*) pneumatic angular drill; *1*—casing; *2*—electric motor; *3*—partition; *4*—reducers; *5*—spindles; *6*—impeller; *7*—trigger; *8*—lock; *9*—eccentric; *10*—pin; *11*—spring; *12*—nipple; *13*—sleeve; *14*—ball; *15*—blade; *16*—rotor; *17*—stator (*A*—hole; *B*—duct)

Figure 8*b* shows a gun-type pneumatic drill which finds a wide application. Forced in aluminium casing *1* of this drill is stator *17* of the pneumatic motor. Rotor *16* has four slots which receive textolite blades *15*. The air for the motor is supplied from the mains along a rubber hose through nipple *12*. Sleeve *13* has ball *14* of a shut-off valve pressed against the sleeve seat by spring *11*.

The air comes through nipple *12* and the hole in the sleeve only with the ball pressed downwards by pin *10*. Flowing through holes *A* in the sleeve the air gets inside the handle and then to the working cavity of the motor through duct *B*. To start the drill, press on eccentric *9* whose end protrudes onto the surface of the handle of casing *1*. The eccentric turns and pin *10* presses ball *14* downwards admitting thus the air from the mains.

At full pressure of air (6 atmospheres) the rotor of the motor runs at a speed of 12,000 rpm. The speed can be reduced through planetary reducer *4* which imparts spindle *5* of the drill 2000 rpm. The maximum drilling diameter is 8 millimetres. The mass of the drill is 1.5 kilograms, its overall size is 210 × 50 × 140 millimetres.

When operating in difficult-of-access places or when drilling at an angle, the drilling machines are equipped with angular adapter heads, or special pneumatic angular drills are used (Fig. 8*c*).

2.4. Power Threading Tools

Power threading tools are similar in design to electric and pneumatic drills but their spindles run at a slower rate, besides they have a spindle reverser and a cam to prevent the breakage of the tap due to overloading. Such tools are used for machine threading threads up to 8 millimetres in diameter (for instance when threading holes for fastening bolts, plugs, locks, etc.).

Figure 9*a* shows a gearing diagram of an electric threading tool which operates as follows. The rotation of rotor *1* of the electric motor is imparted through the reduce to gear wheels *3* and *5* which set freely on spindle *7* and revolve in different directions; working wheel *3* is usually forced to revolve twice as slow as return gear wheel *5*. Spind-

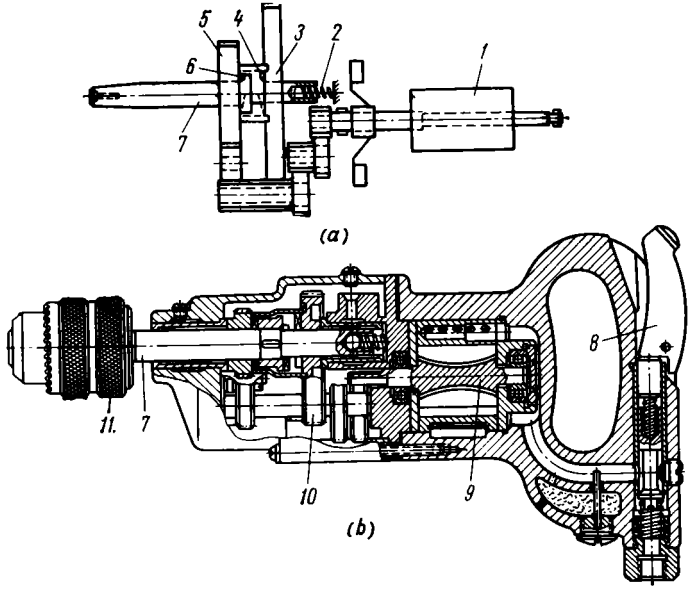

Fig. 9. Power threading tools

(*a*) gearing diagram of electric threading tool; (*b*) pneumatic threading tool; *1*—rotor; *2*—spring; *3*, *5*—gear wheels; *4*, *6*—cams; *7*—spindle; *8*—starter; *9*—pneumatic motor; *10*—reverser; *11*—chuck

le *7* is capable of axial rotation but normally under the action of spring *2* it is in the left-hand extreme position. The spindle is geared to gear wheel *5* by means of a shaped flange, the wheel having cams *6* for the purpose. The tap is fastened in the chuck which is set on the end of spindle *7*.

To start threading, press on the handle of the threading tool. The spindle overcoming the force of spring *2* moves along its axis inside the reducer casing and connects with gear wheel *3* by means of the flange cams, gear wheel *3* having cams for engaging with the spindle. When the pressure is released, spring *2* knocks the spindle out. Thus the latter engages with gear wheel *5* and starts its reverse running at a double speed. All this makes the tap screw go out of the threaded hole.

To avoid slipped threads or broken taps when threading blind holes, use is made of a special device attached to the

threading tool to discontinue the revolutions of the tap as soon as necessary. This device is made in the form of a movable rod set on the tool body parallel to the tap. The ends of the rod and the tap are so spaced as to correspond to the specified threading depth. When the rod presses against the workpiece, the tool will be no longer fed while the tap will go on screwing in the hole making thus the spindle follow it. This will result in disengagement of the spindle and the working gear wheel.

Figure 9*b* shows a pneumatic threading tool for threading holes up to 8 millimetres in diameter. It distinguishes from a pneumatic drill by the presence of a reducer which allows forward and reverse higher-speed run of the tap.

2.5. Power Scrapers

Scraping close contacts between mating surfaces is not very popular in tool making nowadays and is gradually ousted by finish machining (finish grinding, scrape milling by cemented-carbide cutters, fine planing with wide-blade tools, etc.). Such operations require no further treatment except for frosting the surfaces. Scraping can be performed by means of various hand-held power tools.

The widest application had been gained by a light-weight *pneumatic scraper* (Fig. 10*a*) fitted out with cemented-carbide tools. The pneumatic scraper comprises rotor pneumatic motor *1*, planetary gearing *2*, bevel gearing *3*, crank gear *4*, and scraping blade *5*.

Depending on the amount of air fed, the rotor will run at a speed from 8000 to 12,000 rpm, the planetary mechanism reducing the speed tenfold which results in a uniform operation of the gearing and a smooth run of the working tool. The mass of the pneumatic scraper is about 1.5 kilograms.

When scraping large workpieces such as surface plates, a *pneumatic-and-magnetic scraper* is used (Fig. 10*b*). This scraper comprises body *9* with electromagnets *10*, pneumatic motor *1*, reducer *8*, and blade *5*. Rotation from the pneumatic motor is transformed by crank gear *4* into reciprocation of the lever of tool holder *11* whose socket accommodates the scraping blade made of cemented carbide.

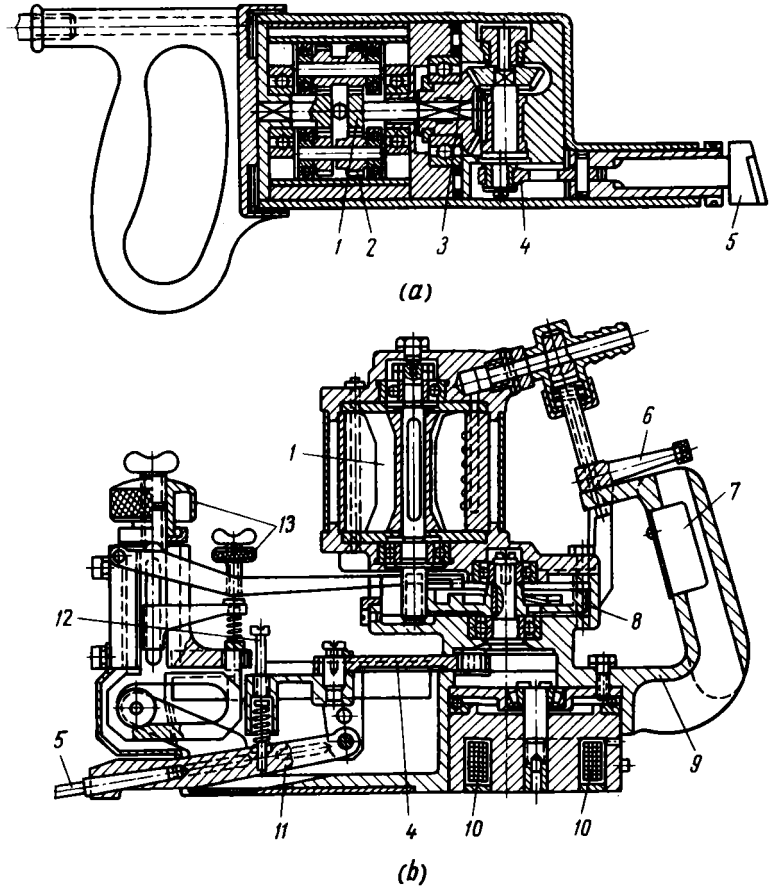

Fig. 10. Power scrapers

(*a*) pneumatic scraper; (*b*) pneumatic-and-magnetic scraper; *1*—pneumatic motors; *2*—planetary gearing; *3*—bevel gearing; *4*—crank gears; *5*—scraping blades; *6*—lever; *7*—microswitch; *8*—reducer; *9*—body; *10*—electromagnets; *11*—tool holder; *12*—screw; *13*—nuts

When microswitch *7* is on, electromagnets *10* operate and the scraper body is pressed against the surface of the workpiece. Screw *12* controls the pressure of the scraper on the surface, while nuts *13* serve to adjust the thickness of

shavings and the blade stroke. The maximum stroke of the blade is 40 millimetres, the number of double strokes per minute is up to 560 (adjusted by lever *6* and pneumatic cocks).

2.6. Power Filing Tools

Filing is done by means of hand-held pneumatically operated tools or by electric tools with a flexible shaft. Much importance is attached to special-purpose filing machines which facilitate the work and provide for high efficiency combined with precision.

A pneumatic file is shown in Fig. 11*a*. The operation principle of the file is based on application of a pneumatic motor and a crank gear. Rotor *8*, via gear wheel *7*, rotates crankshaft *4*. Set on the shaft are connecting rods *3* and *5* mounted on needle bearings *9*. Connecting rod *3* is hinge-joined with working rod *2* having file *1* secured in it, whereas rod *5* is joined with massive balancing slide *6* to dampen the resistance caused by filing. The rotation of crankshaft *4* is transformed into reciprocation of the file and the balancer which ensures smooth jerkless motion of the tool. The mechanism of a pneumatic file is mounted in a cast silumin housing. The rate of motion is 1500 double strokes per minute. The stroke of the file is 12 millimetres. A common practice is to use short files with straight shanks.

Figure 11*b* shows a *power file* driven by the flexible shaft of an electric motor. Its operation principle is based on utilization of a worm gearing and an eccentric. The rotation of flexible shaft *11*, via tip *10*, is imparted to worm *12* which is in mesh with gear wheel *7* whose eccentric pin *13*, via roller *14*, imparts reciprocation to eccentric clip *15* and rod *17* connected with it and mounted in body *16*. The file is secured in the chuck screwed on the shank of rod *17*. The file stroke is 25 millimetres.

When employing small-sized files and needle files use is made of *filing heads for pneumatic drills* (Fig. 11*c*). Body *16* of the pneumatic drill carries adapter *18* while spindle cone *19* carries, instead of the chuck, drum *20* with annular helix groove *G* which receives pin *21* of slide *22* of the adapter. The shank of a needle or an ordinary file is inserted

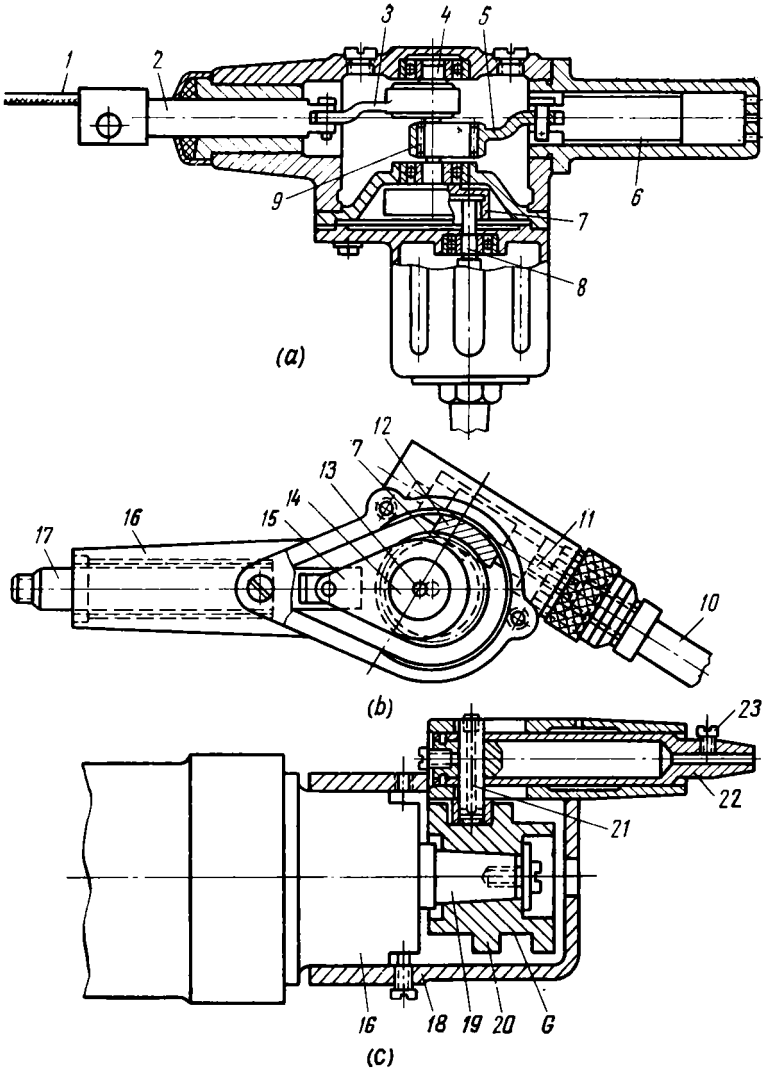

Fig. 11. Hand-held power files

(*a*) pneumatic file; (*b*) power file; (*c*) filing head for pneumatic drill; *1*—file; *2*—working rod; *3*, *5*—connecting rods; *4*—crankshaft; *6*—balancing slide; *7*—gear wheels; *8*—rotor; *9*—needle bearings; *10*—tip; *11*—flexible shaft; *12*—worm; *13*—eccentric pin; *14*—roller; *15*—eccentric clip; *16*—bodies; *17*—rod; *18*—adapter; *19*—spindle cone; *20*—drum; *21*—pin; *22*—slide; *23*—screw

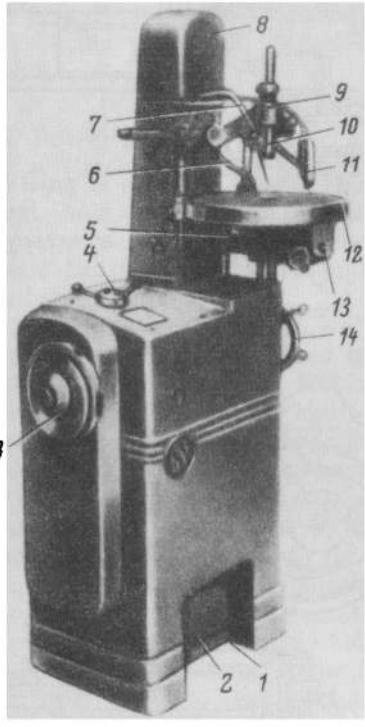

Fig. 12. Filing machine

1, *2*—foot-operated treadles; *3*—gearing; *4*—regulator; *5*—bottom bracket; *6*—lugs; *7*—hose; *8*—casing; *9*—top bracket; *10*—chuck; *11*—lamp; *12*—table; *13*—hinge; *14*—steering wheel

into the central hole of the slide and secured therein by screw *23*. When drum *20* revolves, pin *21* is reciprocated with an amplitude equal to the pitch of the helix of the annular groove. This motion is imparted to the file whose stroke is 10 to 15 millimetres, the number of double strokes per minute is up to 1500. The mass of such a head is 0.5 to 0.6 kilogram, its overall size being 100 × 60 × 50 millimetres.

Filing machines are mostly employed for filing closed contours of components of pressworking dies (female dies of blanking press tools, strippers, articulated punches) as well as contours and reliefs of some components of jigs, fixtures and moulds.

The filing machine (Fig. 12) operates as follows. A machine file with its shank is fixed in chuck *10* of top bracket *9* secured on the movable rod of the machine (not seen due to casing *8*). The other end of the file is set into the chuck of bottom bracket *5* and fixed in it. The distance between the top and bottom brackets is adjusted by moving the top bracket over the rod after which the bracket is locked by a fly nut.

The rod is reciprocated by a link gear. The rod stroke

can be set by regulator *4* in the range of 0 to 120 millimetres, the number of rod strokes being varied by engaging different gearing steps on gearing *3*. Machine table *12* can be moved up and down by 90 millimetres with the aid of steering wheel *14*; it can be tilted to the required side by means of hinge *13*. Two lugs *6* adjustable in height and direction serve for holding the work against the table.

The work is placed on the machine table and fed to the file by hand. When filing a closed contour (for instance, an opening in the die), the file is first inserted into the opening and then secured in the chuck. The position of the file with respect to the table surface is verified by a protractor. If filing is done to obtain a narrow slot, the filing machine is provided with a hacksaw whose ends are made as those in type I file (see Fig. 3).

The filing machines usually operate at 80 to 340 double strokes per minute. When filing tool carbon steels and cast iron the machine is set up for 80 to 120 strokes per minute, while machining structural steels, for 120 to 160 strokes per minute. Sulfofresol or emulsion is used as a coolant when dealing with steel workpieces. To deliver coolants, the machine is provided with a tank and hose *7*. The workplace is illuminated by electric lamp *11* on a flex. The machine is started and stopped by foot-operated treadles *1* and *2*.

The filing machine is normally used for machining those workpieces which have already been handled on metal-cutting machines, such as drilling, slotting, or milling machines with filing allowances from 0.2 to 0.5 millimetre. Filing takes little time but it must be performed very accurately which calls for frequent interruptions of work to measure the workpieces.

2.7. Electrical Flexible-Shaft Machines

A feature of such a tool is a flexible shaft driven from an electric motor. One end of the shaft is connected with the motor, the other carries a chuck with working tools: a rotary file or burr, an abrasive rotary head.

Figure 13*a* shows the design of a widely-used *portable wheeled flexible-shaft machine* which is sometimes called a trimming machine. The power tool comprises upright *7* rest-

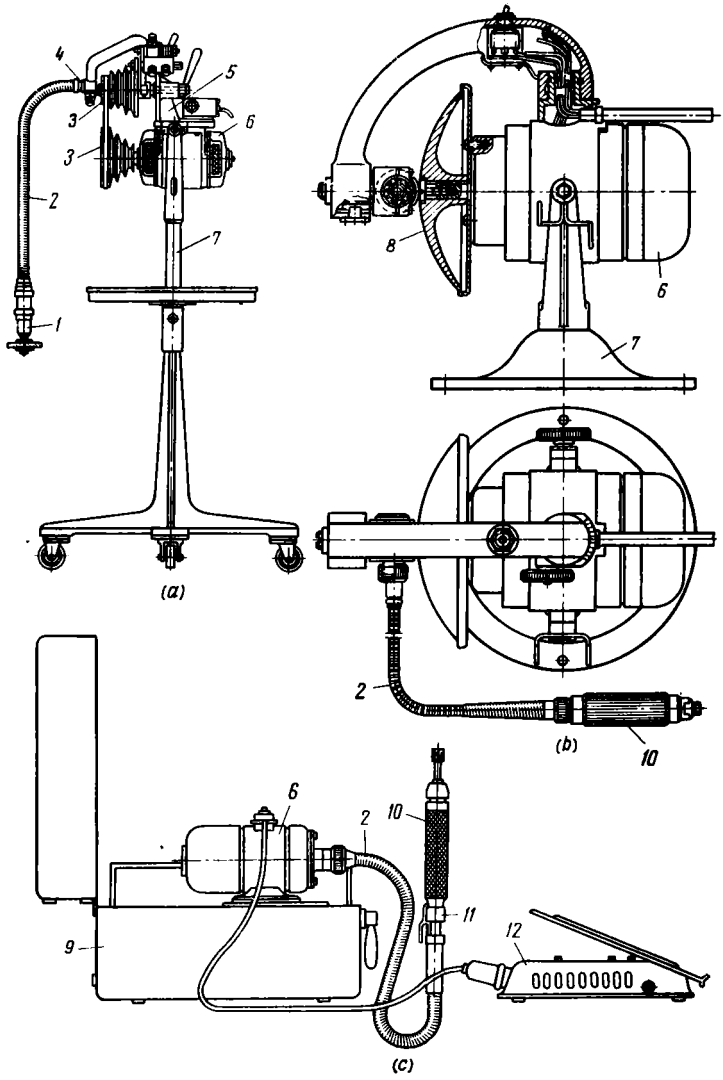

Fig. 13. Electrical flexible-shaft machines

(*a*) portable wheeled machines; (*b*) desk machine; (*c*) portable machine in casing; *1*—adapter; *2*—flexible shafts; *3*—pulleys; *4*—driven shaft; *5*—carrying fork; *6*—electric motors; *7*—uprights; *8*—ball-type speed regulator; *9*—casing; *10*—connection fittings; *11*—lock; *12*—foot treadle

ing on wheels and carrying fork *5* with electric motor *6* hinge-mounted on it. The rotation of the motor shaft is imparted, via two four-stepped pulleys *3* and a V-belt, to driven shaft *4* with flexible shaft *2* connected to it. The end of the flexible shaft carries a collet chuck serving to secure a tool or adapter *1* (head) for a grinding wheel.

By resetting the V-belt the flexible shaft can be forced to run at a speed from 1400 to 6000 rpm which provides for required cutting rate when milling, filing, grinding or trimming the cavities, edges and shape-forming surfaces of dies, jigs and fixtures.

A desk flexible-shaft machine is shown in Fig. 13*b*. A feature of this machine is ball-type speed regulator *8* which allows an infinite variation in the speed of the flexible shaft. This makes it possible to use cutting tools of different size and purpose: rotary files and burrs of up to 12 millimetres, grinding heads of up to 25 millimetres. Electric motor *6* runs at a speed of 2800 rpm and the flexible shaft is imparted a rotation of 2800 to 12,600 rpm. The machine is of a small size (3500 × 250 × 350 millimetres), its mass being as little as 13 kilograms. Upright base *7* has holes to mount the machine on the workbench.

The industry has turned out a *light-weight electrical flexible-shaft grinding machine.* It is shown in Fig. 13*c*. Advantages of such a machine are its small size and portability, as well as small size and light weight of tool-holding attachments, foot treadle *12* for switching on and off the motor and for infinite regulation of its speed.

The mass of the flexible-shaft grinding machine with a set of working and auxiliary tools is about 10 kilograms. The complete machine is accommodated in special casing *9* which is also its base when placing it on the workbench. 50-watt electric motor *6* has adjustable speed. It is supplied from the 200- or 127-volt a.c. mains. The maximum speed of the shaft rotation is 8000 rpm.

Flexible shaft *2* of the machine is detachable and provided with special connection fittings *10* and spring-loaded lock *11*. The latter allows tool-holding attachments to be quickly connected to, or disconnected from, the flexible shaft without disengaging the motor. The shaft runs in the right-hand direction.

For holding the working tools the machine is furnished with two straight collet chuck of similar design but of different size. If necessary the electric motor can be connected with an all-purpose grinding head used for sharpening and lapping small-size fitter's tools (instead of a flexible shaft). Besides, the collet chuck of an all-purpose head can carry working tools which allow trimming, grinding, polishing, lapping and other operations to be performed upon the workpieces held in hand.

2.8. Grinding and Polishing Machines

Hand grinding operations are performed most conveniently by pneumatic hand-held grinders. When the requirements for machining accuracy are not too strict, such grinders can be used to the best advantage for quick removing of stock left as machining allowance. In repairing dies, jigs and fixtures they prove efficient for rounding-off edges, burring, grinding-off dents and rusted spots.

Used as working tools are grinding heads, buffs and discs coated with abrasive cloth, discs charged with abrasive powder, and rotary metal brushes.

The enterprises manufacture for in-hose applications desk grinding-and-trimming machines and make use of different *supports for hand-held power tools* (Fig. 14*a*) whose spindle can be provided with a small-diameter grinding wheel or a steel brush.

A desk machine for hand trimming and grinding flat workpieces is shown in Fig. 14*b*. The main part of such a machine is electric motor *8* mounted vertically in special housing *7*. The top end of the motor shaft carries abrasive face wheel *3* and fan *2*. The workpiece with its surface to be ground is placed on the top of cover *4* and moved over it bringing into the contact with the wheel face. The moving workpiece is stopped by rest *6*. The abrasive dust and metal shavings are withdrawn through receiver *5* and duct *9* into dust collector *10*. The wear of the abrasive wheel is compensated for by periodically turning adjusting thread ring *1* which lowers the housing and cover *4*.

A hand-held surface-grinding machine intended for grinding the guide surface when repairing machine tools, dies,

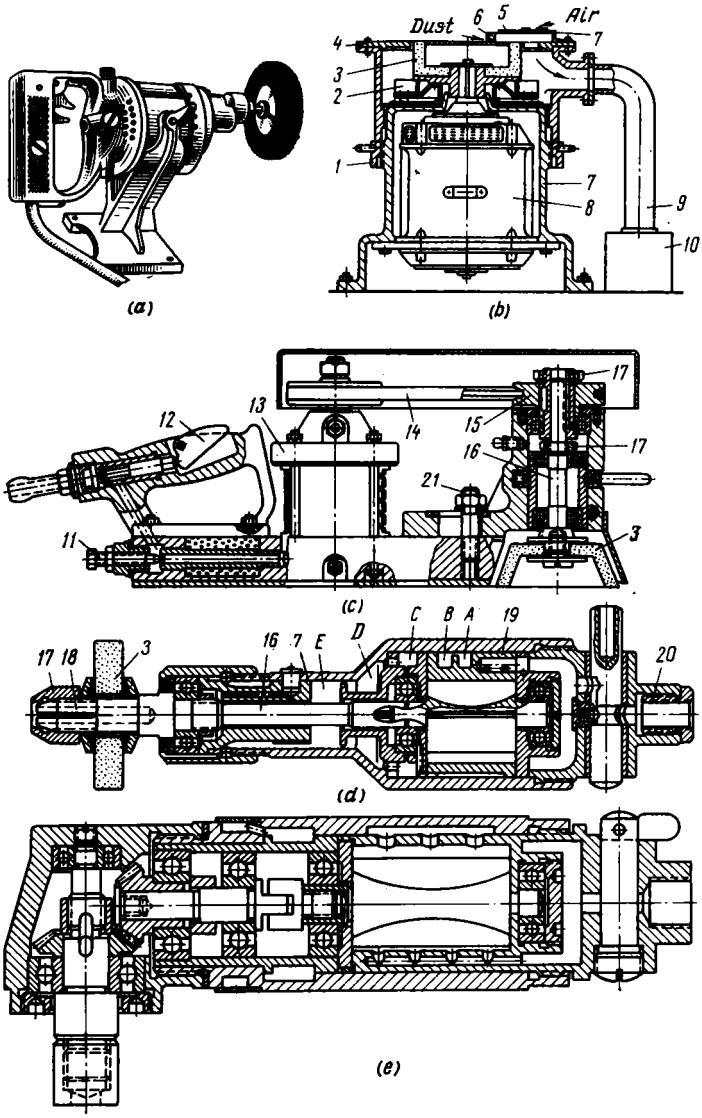

Fig. 14. Grinding and polishing machines

(*a*) electric drill converted into grinding-and-triming machine; (*b*) desk machine for trimming and grinding; (*c*) hand-held surface-grinding machine; (*d*) hand-held pneumatic grinding-and-polishing machine; (*e*) angular grinding-and-polishing machine; *1*—thread ring; *2*—fan; *3*—abrasive wheels; *4*—cover; *5*—receiver; *6*—rest; *7*—housings; *8*—electric motor; *9*—duct; *10*—dust collector; *11, 21*—screws; *12*—trigger; *13*—pneumatic vane-type motor; *14*—V-belt; *15*—pulley; *16*—spindles; *17*—nuts; *18*—collet chuck; *19*—pneumatic motor; *20*—adapter

jigs and fixtures (Fig. 14*c*) offers good convenience in operation and allows quick reconditioning of worn-out surfaces in heavy steel and cast-iron parts restoring their flatness. This considerably cuts the scraping work especially when making surface plates.

The power of pneumatic vane-type motor *13* is up to 1.4 h.p. with air pressure in the mains of 6 atmospheres. The rotation is transferred by means of V-belt *14* from the motor to pulley *15* set up on the upper end of machine spindle *16*. The opposite (lower) end of the spindle carries cup shaped abrasive wheel *3*. By manipulating nuts *17* the spindle is adjusted in height which determines the amount of the stock to be removed from the worn-out surface, screw *21* is used to adjust the spindle overhang in accordance with the diameter of the abrasive wheel. Screw *11* is used to vary the spindle speed by changing the size of the opening which admits compressed air, the maximum speed being 4200 rpm. The overall size of the machine is 510 × 150 × 190 millimetres, the mass being 12 kilograms. The air feed is engaged and disengaged by pressing on trigger *12*.

Figure 14*d* shows an *all-purpose grinding-and-polishing machine* which is also driven from the mains of compressed air fed through the hose connected to adapter *20*. Pneumatic motor *19* of the hand-held machine, accommodated in housing *7*, drives spindle *16* whose front end can be used to secure grinding or polishing wheel *3* having a central hole. The front end of the spindle is made in the form of collet chuck *18* which is clamped with tapered nut *17* allowing thus an abrasive or diamond head to be attached. The same nut is used to secure wheel *3*.

An advantageous feature of this hand-held machine is its noiseless operation, the noise being silenced by repeated compression and expansion of used up air. The air compressed in the exhaust ports of the motor stator expands in chamber *A* and then compresses in the annular gap to expand again in chamber *B*. When getting into the next chamber the air is first compressed and then expands in chambers *C*, *D*, and *E* while complete expansion takes place when it escapes to the atmosphere.

The speed of a loaded spindle is up to 8000 rpm. The diameter of commonly used wheels is up to 50 millimetres, that

of grinding heads up to 25 millimetres. The developed power is 0.25 h.p. with air pressure of 6 atmospheres. The overall size of the machine is 250 × 45 × 75 millimetres, the mass being 1 kilogram.

Angular grinding-and-polishing hand-held machines of different designs and sizes (Fig. 14*e*) are used in difficult-of-access places. The machine, similar to the above described, is driven from the compressed-air mains. The rotation is transferred to the working spindle at an angle of 90° via a pair of bevel gears. The spindle can carry grinding heads of up to 20 millimetres in diameter. The idle speed of the spindle is up to 10,000 rpm. The highest power of the spindle is 0.27 horse power. The mass of machine is 1.7 kilograms, the overall size being 190 × 60 × 85 millimetres.

A stand for grinding pneumatic machine. When employing a pneumatic hand-held machine or a machine with a flexible shaft, the work is usually clamped in the vice or positioned on the bench whereas the tool is manually moved with respect to the surface to be machined.

Due to non-uniform removal of stock crests arise on the surface being machined. This calls for frequent tests of the surface for being flat (to the rule) and for checking whether the angle specified in the drawing is observed (to a try square or a protractor).

Figure 15 shows the stand which cuts machining time, makes the operation easier, and facilitates the inspection.

The stand comprises solid base *1* with post *2* and rack *3* forced in it, the rack also serves as a key. The key prevents bracket *4* from turning when it travels over the post by means of shaft *6* with a gear wheel on its end. Pneumatic head *11* is secured vertically in the flap clamps *10* and *12*. Holder *8* arranged in the top part of bracket *7* in combination with nut *9* allows regulation of the pneumatic head tilt (which means regulation of the grinding wheel tilt) from the vertical axis or positioning of the head at some angle with respect to the plane of base *1*. This stand makes it possible to machine vertical surfaces of holes in press-working dies and moulds with a draft of up to 3-4°.

For truing the grinding wheel a diamond is inserted in a T-shaped slot *14* of base *1*. The truing is performed by lifting and lowering bracket *4* by means of a steering wheel set

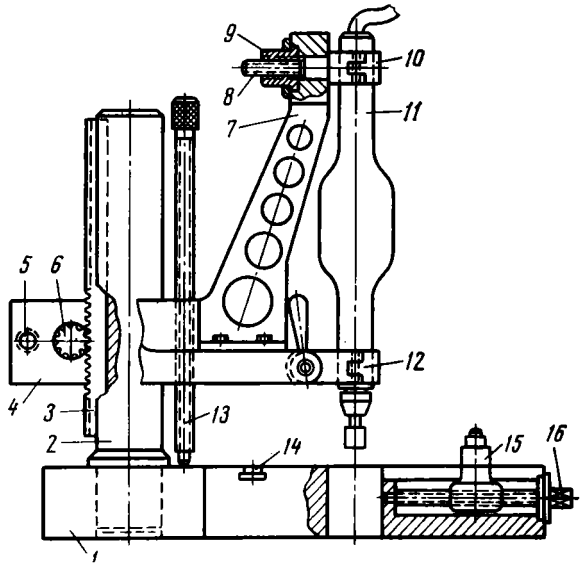

Fig. 15. Bench stand for grinding pneumatic machine
1—base; *2*—post; *3*—rack; *4*, *7*—brackets; *5*, *13*, *16*—screws; *6*—shaft; *8*—holder; *9*—nut; *10*, *12*—clamps; *11*—pneumatic head; *14*—slot; *15*—rest

on shaft *6*. The bed and the pneumatic head, positioned at the required level, are locked by screw *13* whose end rests against base *1*. The entire arrangement is stopped by screw *5* with a handle.

When grinding the slope of a part the pneumatic head may be tilted from the vertical only after the wheel has been trued with a diamond. For a convenient transfer of the work with respect to the grinding wheel the stand is provided with movable rest *15* moved by screw *16*.

When handling rectilinear surfaces the work is manually transferred along the rest using it as a base, and a uniform stock is removed from the surface being machined. The work is fed to the wheel by means of screw *16*. The shaped workpieces are ground and polished using manual feed, without a rest.

A circular grinding-and-lapping machine which allows the surfaces to be machined with the aid of a cast-iron wheel charged with abrasive powder is shown in Fig. 16.

Grinding wheel *1* is set upon the shaft of an electric motor which is vertically mounted inside solid cast bed *2*. With

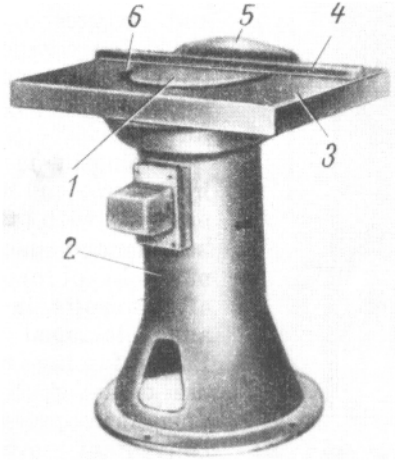

Fig. 16. Circular grinding-and-lapping machine
1—grinding wheel; *2*—bed; *3*—table; *4*—plank; *5*—dust sucker; *6*—plastic ring

the aid of a handwheel, which is on the rear of the bed, the wheel can move vertically to be flush with table *3* and so as to use the wheel periphery. The work being ground is pressed against plank *4* arranged along the table. Behind the plank there is dust sucker *5*. Between wheel *1* and the hole of table *3* there is a forced-in plastic ring *6*.

A lapping-and-honing machine (Fig. 17) is intended for lapping shaped holes and outside surfaces in the components of dies, jigs and fixtures, consisting of straight pieces and arcs, the operation being performed with the aid of lapping blocks and abrasive materials. This machine is similar in design to a filing machine, but in addition to reciprocation, the round lapping tools can perform rotation.

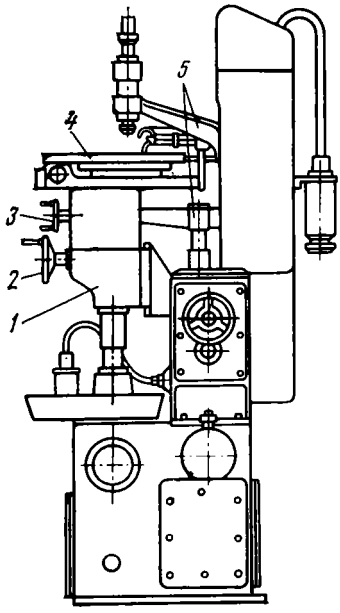

Fig. 17. Lapping-and-honing machine

1—bracket; *2*—turning handwheel; *3*—table-tilting handwheel; *4*—master table; *5*—bracket

The machine ensures high precision and good surface finish.

2.9. Forcing-In Devices

When assembling dies, jigs and fixtures and similar articles the components are often joined to one another with interference, *i.e.*, they are forced-in.

Forcing-in is accomplished by presses or by an impact method with the aid of a hammer and spacers. The latter method is of low efficiency and often results in wrong joints and damaged components. Power forcing-in involves the use of lever, hydraulic, and pneumatic presses. The most convenient are hydraulic presses developing adequate force, providing the required rate of loading, and ensuring accurate mounting of workpieces to be forced-in. The tool shops usually employ small-sized hydraulic presses with rated force from 10 to 100 kilonewtons.

Figure 18 shows a bench lever-and-hydraulic press intended for assembling jobs. This press can operate as a standard lever mechanism (manually loaded) by means of a steering wheel (when necessary to exert a slight pressure on the workpiece being mounted and verified). In this case the force developed by the slide may be as much as 12.5 kilonewtons. When the hydraulic system is combined with a hand pump delivering oil, the press will develop a force of up to 50 kilonewtons. The press is mounted on a workbench or on a separate small pedestal.

2.10. Safety Rules

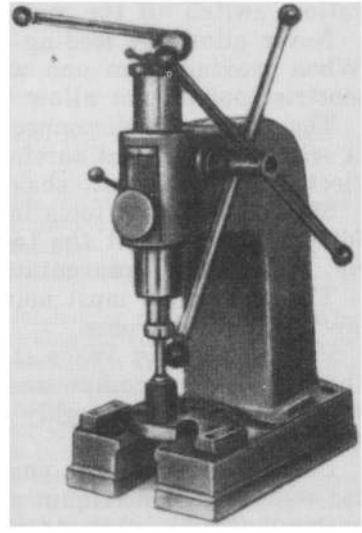

Fig. 18. Bench lever-and-hydraulic press for assembling jobs

Electric tools. Never start operating an electric tool without having made sure of its good working order. First check up whether every part of the tool is properly secured in its place, then run the movable parts and units by hand to see whether they run easily and smoothly and whether they are adequately lubricated. Special attention should be paid to check whether the feed hose is in order and its insulation is intact.

When checking up the switching-on system, first make sure whether the rated voltage and frequency of the electric motor correspond to those available from the mains. See to that the motor and tools are earthed (or neutral grounded) if the working voltage exceeds 65 volts. The switch is checked by repeated idle switching on and off, then the tool is connected to the mains and switched on and off again several times.

When operating any electric tool always preclude its overheating. The heat is considered permissible if your hand applied to the tool body can stand it.

Always use the cutting tools which are designed for work with the particular size and kind of electric tool. Never start working unless having made sure of perfect order of the cutting tool and its secure attachment in the chuck.

Never adjust the tool or remedy its faults, etc. with the electric motor engaged. For any repair disconnect the feeding lead of the electric tool from the mains.

Switch on the electric motor immediately before the operation; switch off the motor for intervals in work.

Never allow the feeding lead to be damaged or twisted. When moving from one workplace to another with your electric tool do not allow the lead to stretch.

The work over, disconnect the lead from the mains, wipe it with dry rag, and carefully wind it up. Then clean the electric tool off dust, shavings, dirt, and oil.

Store the electric tools in closed boxes. If there are long idle periods, submit the tool to a store-room for checking up, lubrication, preventative repair, and storage.

The tool maker must neither disassemble, nor repair the electric tools he uses.

Pneumatic tools. When starting work, before you connect the hose feeding compressed air to the pneumatic tool scavenge the hose thoroughly with compressed air to remove dust and dirt from it.

Before operation, the pneumatic tools should be lubricated well with clean liquid mineral oil. The percussive tools without special lubricators should be oiled at least twice during a working shift by pouring oil into them through the hole in threaded sleeves.

See to that the oil does not get inside or outside the hose since it may destroy the rubber.

The crankshaft and gearing in the hand-held drills should be greased with consistent grease (chassis lubricant, solid oil). Such lubricants are replenished through the available lubricators when necessary.

Always connect the rubber hose to the pneumatic tools before compressed air is fed, i.e., start delivery of compressed air only when the tool is already connected to the line.

Start operation of the pneumatic tools only after the working tip is inserted in its place.

The work over, first stop the admission of compressed air into the feed hose of the pneumatic tool and then disconnect the hose from the pipeline and the tool.

Do not disconnect the tool from the hose with compressed air still admitted into the hose since air pressure may make you drop the hose and thus hurt those standing nearby.

The tool maker must neither disassemble, nor repair the pneumatic tools he uses.

Chapter 3

Materials

3.1. Steels

In the manufacture of dies, moulds, jigs and fixtures as well as other pieces of tooling, use is made of different materials, some of them possessing special properties.

The critical parts of dies and moulds are made of carbon and alloy tool steels which fall into three basic groups:

(1) die steels for deforming cold metals;

(2) die steels for deforming hot metals and for moulds;

(3) corrosion-resistant die steels.

The steels of the first group are intended for making pressworking dies. After final heat treatment the working surfaces and cutting edges of parts made of such steels should possess high hardness, resist wear so well as to preserve the shape and size of the working edges in the maintenance of a die. They should provide for good strength of both the working edge acting upon the material to be pressed and the sections of a die which receive maximum bending and torque loads.

The steels of the second group should retain high mechanical properties at elevated temperatures. Their heat treatment is aimed at obtaining high viscosity with lower hardness as compared with the steels of other groups.

The steels of the third group are intended for making moulds, for work on plastics and pressure casting. In addition to the properties of the steels of the second group they should be resistant against aggressive media (chemically-active plastics, aggressive alloys).

What is most important for die steels of all grades is to combine good hardness and high viscosity.

The die steels are also expected to possess special manufacturing properties, such as:

(a) good workability, i.e., ability of being readily cut, pressworked, and drop forged;

(b) good hardenability, i.e., offering high and uniform hardness, homogeneous fine crystal structure when cooled off;

(c) low sensitivity to overheating which allows hardening under a wide range of temperatures;

(d) low deformation of parts under heat treatment;

(e) low sensitivity to decarbonization due to heating which reduces the hardness of the surface (working) layer of metal;

(f) good grindability which governs the high quality of the ground surface and the efficiency of grinding operations.

Carbon Tool Steels

The carbon tool steel is an iron-carbon alloy with a content carbon from 0.65 to 1.35 per cent. Manganese, silicon, sulphur, phosphorus, and oxygen are constituents of carbon steels.

Carbon tool steels are available in the USSR in the following sixteen grades: У7, У7А, У8, У8А, У8Г, У8ГА, У9, У9А, У10, У10А, У11, У11А, У12, У12А, У13, and У13А.

The letters and digits in the designations of steel grades have the following meaning: У designates carbon; the digit next to the letter denotes the mean content of carbon (in tenth fractions of per cent); А stands for high-quality cast (with the least possible content of harmful impurities); Г stands to show high content of manganese.

Higher content of carbon in steel contributes to its hardness and strength but reduces its plasticity. This is why the steel grades with higher content of carbon (У11, У12, У13) which get very brittle after hardening find practically no application in making dies or moulds. Nor is grade У9 steel good for this purpose since its heating results in coarser grains while in strength and plasticity it is inferior to grade У10.

Though very hard after heat treatment, carbon tool steel is essentially disadvantageous in many respects, the major limitations being:

(1) poor resistance to wear and low red hardness (when heated to the temperature exceeding 250°C this steel loses its hardness);

(2) non-through hardenability due to which the hardness in medium layers is much lower than on the surface;

(3) liability to forming cracks, shrinkage, and considerable warps when heat-treated;

(4) low resistance to corrosion, especially when heated.

All this makes carbon tool steels applicable only for manufacturing tools operated under low loads, for work on soft metals and alloys, and where no strict requirements are extended to the products.

Table 1 shows chemical composition and properties of some grades of carbon tool steel most popular in manufacture of the parts of dies, moulds, jigs and fixtures.

Table 1

Composition and Properties of High-Quality Carbon Tool Steels

Grade	Chemical composition in per cent*				Hardness			Hardening temperature, °C
	Carbon C	Manganese Mn	Silicon Si	Sulphur S	Phosphorus P	Maximum hardness Bhn of green steel	R_c of water-quenched steel	
У7А	0.65-0.74	0.15-0.30	0.15-0.30	0.02	0.03	187	60-63	800-820
У8А	0.75-0.84	0.15-0.30	0.15-0.30	0.02	0.03	187	61-63	780-800
У8ГА	0.80-0.90	0.35-0.60	0.15-0.30	0.02	0.03	187	61-63	780-800
У9А	0.85-0.94	0.35-0.60	0.15-0.30	0.02	0.03	192	62-64	760-780
У10А	0.95-1.04	0.15-0.30	0.15-0.30	0.02	0.03	197	62-64	760-780

* In addition to the above elements the following residual alloying elements may be present: chromium (Cr)–0.15 per cent, max; nickel (Ni)–0.20 per cent, max; copper (Cu)–0.20 per cent, max.

Alloy Tool Steels

The alloy tool steel composition incorporated specially introduced (alloying) elements, absent in carbon steel. These elements influence physico-mechanical and manufacturing properties of steel.

They change hardness, strength, viscosity, wear resistance, corrosion resistance, heat conductivity, thermal expansion coefficient, and other properties of metal.

A change in the properties of steel due to alloying depends not only upon composition and quantity of alloying elements but also upon the way they interact with iron and carbon as well as with one another. Good influence of alloying elements upon the properties of steel is especially conspicuous after heat treatment.

Owing to alloying elements the alloy tool steels have the following advantages in comparison with carbon tool steels: higher viscosity when hardened; deeper hardenability; lesser liability to warping, cracking, and variation in size during hardening. Their wear resistance and red hardness are also much higher.

In the USSR, the grades of alloy steels are designated by Russian letters and digits, each widely used chemical element being conferred a definite letters:

Б — niobium (Nb)	П — phosphorus (P)
Ба — barium (Ba)	Р — boron (B)
В — tungsten (W)	С — silicon (Si)
Г — manganese (Mn)	Т — titanium (Ti)
Д — copper (Cu)	У — carbon (C)
Е — selenium (Se)	Ф — vanadium (V)
К — cobalt (Co)	Х — chromium (Cr)
М — molibdenum (Mo)	Ц — zirconium (Zr)
Н — nickel (Ni)	Ю — aluminium (Al)

The other Russian letters are used for the following designations: А, standing at the end of the grade designation, denotes high quality (higher purity with respect to content of sulphur and phosphorus and better mechanical properties); А, standing at the beginning of the grade designation, denotes free-cutting steel; Р, standing at the beginning of the grade designation, denotes high-speed tool steel; Ш — ball-bearing steel; Ж — stainless chromium steel; Я — stainless chrome-nickel steel; Е — electrical steel.

In the designation of grades of alloy tool steels the digit to the left of the letter stands for a mean content of carbon in tenth fractions of per cent. If the quantity of carbon exceeds 0.9 per cent, it is not mentioned. The digits following the letters show the content of the alloying element in per cent.

For instance: 9Х — alloy tool steel with a carbon content of 0.9 per cent and 1 per cent chromium;

Х12 — alloy tool steel with a carbon content of more than 0.9 per cent and 12 per cent chromium;

Table 2

Composition of Alloy Tool Steels and Alloys

Grade	Chemical composition, per cent								
	C	Mn	Si	Cr	Ni	W	V	Mo	Ti
X	0.95-1.10	0.15-0.40	0.15-0.35	1.30-1.65	—	—	—	—	—
X12	2.00-2.00	0.15-0.40	0.15-0.35	11.5-13.00	—	—	—	—	—
X12M	1.45-1.65	0.15-0.40	0.15-0.35	11.0-12.50	—	—	0.15-0.30	0.40-0.60	—
X12Ф	1.40-1.60	0.15-0.40	0.15-0.35	11.0-12.50	—	—	0.20-0.40	—	—
X12Ф1	1.20-1.45	0.15-0.40	0.15-0.35	11.0-12.50	—	—	0.70-0.90	—	—
XГ	1.30-1.50	0.45-0.70	0.15-0.35	1.30-1.60	—	—	—	—	—
XВГ	0.90-1.05	0.80-1.10	0.15-0.30	0.90-1.20	—	1.20-1.60	—	—	—
XВСГ	0.95-1.05	0.60-0.90	0.65-1.00	0.60-1.10	—	0.70-1.00	0.05-0.15	—	—
X6ВФ	1.05-1.15	0.15-0.40	0.15-0.35	5.50-7.00	—	1.10-1.50	0.40-0.70	—	—
3X13	0.25-0.35	up to 0.60	up to 0.60	12.00-14.00	up to 0.60	—	—	—	—
3X2B8	0.30-0.40	0.20-0.40	up to 0.35	2.20-2.70	up to 0.30	7.50-9.00	0.20-0.50	—	—
4X8B2	0.35-0.45	0.20-0.40	up to 0.35	7.00-9.00	up to 0.30	2.00-3.00	—	—	—
4XB2C	0.35-0.45	0.20-0.40	0.60-0.90	1.00-1.30	up to 0.30	2.00-2.50	—	—	—
4XC	0.25-0.45	up to 0.40	1.20-1.60	1.30-1.60	up to 0.30	—	—	—	—
5XB2C	0.45-0.54	0.15-0.40	0.50-0.80	1.00-1.30	up to 0.35	2.00-2.50	—	—	—
5XHM	0.50-0.60	0.50-0.80	up to 0.35	0.50-0.80	1.40-1.80	—	—	0.15-0.30	—
5XГM	0.50-0.60	1.20-1.60	0.25-0.65	0.60-0.90	—	—	—	0.15-0.30	—
5XHB	0.50-0.60	0.50-0.80	0.15-0.35	0.50-0.80	1.40-1.80	—	—	0.60-1.00	—
5XHCB	0.50-0.60	0.30-0.60	0.60-0.90	1.30-1.60	0.80-1.20	—	—	0.40-0.60	—
5XHT	0.50-0.60	0.50-0.80	up to 0.35	0.90-1.25	1.40-1.80	—	—	—	0.08-0.15

5XHC	0.50-0.60	0.30-0.60	0.60-0.90	1.30-1.60	0.80-0.20	—	—	—	—
7XΦ	0.63-0.73	0.30-0.60	0.15-0.35	0.40-0.70	—	—	0.15-0.30	—	—
7X3	0.60-0.75	0.20-0.40	up to 0.35	3.20-3.80	up to 0.30	—	—	—	—
8X3	0.76-0.85	0.20-0.40	up to 0.35	3.20-3.80	up to 0.30	—	—	—	—
8XΦ	0.75-0.85	0.20-0.40	0.15-0.35	0.50-0.80	—	—	0.15-0.30	—	—
9XC	0.85-0.95	0.30-0.60	1.20-1.60	0.95-1.25	—	—	—	—	—
9XΦ	0.80-0.90	0.30-0.60	0.15-0.35	0.40-0.70	—	—	0.15-0.30	—	—
9XBГ	0.85-0.95	0.90-1.20	0.15-0.35	0.50-0.80	—	0.50-0.80	—	—	—
13XH2A	0.09-0.15	0.30-0.60	0.20-0.40	0.60-0.90	1.50-2.00	—	—	—	—
12XH3A	0.09-0.15	0.30-0.60	0.20-0.40	0.60-0.90	2.75-3.15	—	—	—	—
12X2H4A	0.09-0.15	0.30-0.60	0.20-0.40	1.25-1.65	3.30-3.70	—	—	—	—
20XA	0.17-0.23	up to 0.60	up to 0.35	0.70-1.0	—	—	—	—	—
38XA	0.35-0.41	0.50-0.80	up to 0.35	0.80-1.10	—	—	—	—	—
40X	0.36-0.43	0.50-0.80	up to 0.35	0.81-1.10	—	—	—	—	—
30XГCA	0.32-0.35	0.80-1.10	0.90-1.20	0.80-1.10	up to 0.40	—	—	—	—
50Г	0.47-0.55	0.50-0.80	0.20-0.40	up to 0.25	up to 0.25	—	—	—	—
60Г	0.57-0.65	0.70-1.00	0.20-0.40	up to 0.25	up to 0.25	—	—	—	—
65Г	0.62-0.70	0.90-1.20	0.20-0.40	up to 0.25	up to 0.25	—	—	—	—
ШX9	1.00-1.10	0.20-0.40	0.17-0.37	0.90-1.20	—	—	—	—	—
ШX15	0.95-1.05	0.20-0.40	0.17-0.37	1.30-1.65	—	—	—	—	—
P9	0.85-0.95	up to 0.40	up to 0.40	3.80-4.40	—	8.50-10.00	2.00-2.60	—	—
P18	0.70-0.80	up to 0.40	up to 0.40	3.80-4.40	—	17.50-19.00	1.00-0.40	—	—
Sormite-1	2.50-3.30	1.50	2.80-3.50	25.00-31.00	3.00-5.00	Fe-remainder	—	—	—
Sormite-2	1.50-2.00	1.00	1.50-2.20	13.00-17.00	1.32-2.00	Fe-remainder	—	—	—

Note. Not more than 0.03 per cent sulphur (S) or phosphorus (P) is permissible for all grades of steel.

4XB2C — alloy tool steel with carbon content of 0.4 per cent, about 1 per cent chromium, 2 per cent tungsten, and about 1 per cent silicon.

Structural Steels

Structural steels are available in one of the four classes:

(1) ordinary carbon structural steels of the following grades: Ст. 0, Ст. 1, Ст. 2, Ст. 3, Ст. 4, Ст. 5, Ст. 6, and Ст. 7;

(2) quality carbon structural steels with normal content of manganese of the following grades: 10, 15, 20, 25, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, and 85;

(3) quality carbon structural steels with a higher content of manganese of the following basic grades: 15Г, 20Г, 25Г, 30Г, 35Г, 40Г, 45Г, 50Г, 60Г, 65Г, and 70Г;

(4) alloy structural steels of the following basic grades: 15X, 20X, 30X, 35X, 40X, 45X, 50X, 30XM, 35XM, 20XГ, 35XГ2, 40XH, 45XH, 50XH, 20XГС, 30XГС.

Table 2 shows the chemical composition of most popular grades of alloy steels referred to in this book.

3.2. Cast Irons

A number of parts in technological equipment are made from gray cast iron. Cast iron is mostly applied as castings for housing and supports of attachments as well as for support plates in some structures of moulds for plastics.

Gray cast iron is specified by the letters СЧ (the initials of the Russian words for gray cast iron) followed by two figures spaced by a dash. The first figure indicates ultimate tensile strength — σ_u in megapascals, the other transverse strength — σ_t in megapascals.

For instance, the grade СЧ24-44 stands for gray cast iron with the ultimate tensile strength of 240 megapascals and the transverse strength of 440 megapascals.

In tool-making practice, four high grades of cast iron are mainly used: СЧ24-44, СЧ28-48, СЧ32-52, and СЧ35-56.

The castings of gray cast iron should have a gray fracture of a uniform medium-coarse structure.

Since cast iron can dampen vibrations and is of low sensitivity to cuts, it is a valuable structural material while its good machinability makes castings very useful in manufacturing various pieces of tooling equipment. The machine designers make good use of cast iron capacity of holding lubricants in its pores by employing this material for parts working under friction.

3.3. Cutting Alloys

Cutting alloys (also hard alloys) are alloys of high hardness and good heat resistance under elevated temperatures (1000 to 1100°C).

Cutting alloys are made of a powdery mixture of tungsten and

titanium carbides and metallic cobalt by compacting and subsequent sintering. The manufacture of such cutting alloys has much in common with that of ceramic articles, that is why they are also known as cemented carbides.

Some grades of cemented carbides possess good manufacturing properties and high resistance to impacts, vibrations, and crushing which makes them applicable for making tools used in cold-upsetting machinery, critical parts of dies for cold impact stamping and some parts of tooling subject to severe wear and tear.

Cemented carbides are classified into three groups: tungsten-cobalt (BK), titanium-tungsten (TK), and titanium-tantalium-tungsten (TTK).

Cemented carbides, especially those of a BK group, are very strong (the transverse strength from 1000 to 2000 megapascals) and very hard (from 82 to 91 R_A). These qualities depend on the cobalt content: the more cobalt present, the higher the transverse strength and the lower the hardness.

The alloys become less brittle with an increase of cobalt content. The BK alloys are more viscous than those of the TK and TTK groups with equal amount of cobalt in all of them.

The BK group of cemented carbides includes the following grades: BK2, BK3M, BK4, BK4B, BK6, BK6M, BK6B, BK8, BK8B, BK10, BK15, BK20, BK25, and BK30*. The figures following the letters stand for the percentage of cobalt present in the alloy.

For instance, the alloy grade BK6 contains 6 per cent cobalt, the remainder is tungsten carbide.

In manufacturing the parts of tooling equipment cemented carbides are used in the following cases:

BK6 — for punches and female dies for pressworking, working parts subject to rapid wear of machine tool attachments and accessories working under friction (machine tool centres, etc.);

BK8 — for cold-upsetting dies, piercing tools, drawing and sizing dies (for work on steels, non-ferrous metals, and their alloys), parts subject to rapid wear and working under friction, guides subject to much wear, etc.; BK10 — for parts of upsetting, piercing and bending dies working under moderate loads, drawing and sizing dies for work on steel, parts of jigs and fixtures subject to rapid wear;

BK15 — for parts of dies working under moderate impacts, upsetting and piercing tools working under elevated strains, steel-rod- and steel-pipe drawing dies working under elevated upsetting.

BK20 and BK25 — for parts of dies working under heavy impacts.

For reinforcement of working parts of dies use is made of cemented carbides shaped as bars, plates or discs of required size.

The industry also uses cast cutting alloys available in rods of 6 or 7 millimetres in diameter and 400 to 500 millimetres long. These are intended for hard-facing the surfaces of dies and cutting tools subject to rapid wear by means of acetylene-oxygen flame.

This group includes stellites based on chromium, tungsten, and cobalt, and stellite-like alloys (Sormite-1, Sormite-2) based on chromium and iron.

* BK stand for the Russian words for tungsten and cobalt.

3.4. Abrasives for Lapping and Polishing

Abrasives include fine-crushed substances in the form of grains and powders obtained by crushing natural or synthetic materials.

The abrasives used for treatment of metals are classified into two groups: hard and soft.

The former comprise crushed minerals, natural or man-made, possessing high hardness. The latter include fine-crushed powders of different metal oxides, such as chromium oxide, ferric oxide (crocus), aluminium oxide, as well as calcium oxide (French chalk), chalk, talc, tripoli, diatomite.

Hard abrasives are used when large stock is to be removed to obtain the work of the required size.

The most important property of these materials is their hardness. The degree of hardness in abrasives can be determined in different ways, the most simple being that of scratching in which the material of the scratching body should be harder than that of the body being scratched. For this method the Mohs ten-number scale is available according to which the diamond hardness is taken to be 10 numbers and that of talc is 1 number, the other materials occupying the intermediate positions on the scale.

Lapping is done with grinding powders and micropowders or pastes based thereon, for polishing only pastes are applicable.

As to the size of their grains, hard abrasives are classified into groups (Table 3).

Table 3

Grain Size of Abrasives

Abrasives	Grain size	Notes
Grinding grain	200, 160, 125, 100, 80, 63, 50, 40, 32, 25, 20, 16	Grinding wheels, abrasive whetstones, emery cloth
Grinding powders	12, 10, 8, 6, 5, 4, 3	Fine-grained grinding wheels, lapping whetstones, lapping powders
Micropowders	M40, M28, M20, M14, M10, M7, M5	Finish laps

Note. For grinding grains and powders the grain size is measured in hundredths of millimetre, for micropowders in thousandths of millimetre.

Soft abrasives are used for final finishing of the working surfaces of tooling equipment. Polishing materials can be natural or synthetic.

Natural polishing materials include crocus, chalk, talc, French chalk, tripoli, diatomite, kaolin; synthetic materials are oxides of chromium, iron, and aluminium.

All the above soft abrasives are used for finishing and polishing mainly as pastes applied on the surface of laps or mating parts.

Used as bonding agents for making pastes are wax, stearin, paraffin, oleic acid, split fat, castor oil, kerosene, and gasoline. Occasional use can be also made of turpentine, fish oil, dehydrated beef tallow, lard, colophony, and non-drying vegetable oils.

A wide application is gained by the pastes worked out at the Leningrad State Optical Institute (ГОИ). A feature of ГОИ pastes is the presence of components which influence chemically the surface layers of the metal treated and form on them a very thin film of oxides, which is easily removed later on by abrasive grains.

The ГОИ pastes are available in three groups: a coarse paste of light-green colour used for removing allowances of tenth fractions of millimetre; a medium paste of green colour for removing allowances of hundredth fractions of millimetre; and a fine paste of black colour with a greenish tint used for removing allowances of thousandth tractions of millimetre and imparting mirror-like brightness to the surface of the work.

3.5. Diamonds and Diamond Pastes

The tool makers use diamonds in the form of crystals, powders or pastes. The largest grains (630 microns and over) are used for making cutting tools and for heat treatment of hardened steels; the grains from 200 to 50 microns are employed in the manufacture of grinding wheels, bars, diamond needle files, and laps for treatment of hardened steels and hard alloys, the finest diamond powders (finer than 1 micron) go for making finishing and polishing pastes.

Both natural and man-made (synthetic) diamonds are extensively used in industry. As to their working capacity the synthetic diamonds (under certain conditions) are not inferior, and often even superior, to natural ones. This is owing to their good uniformity and special surface of grains contributing to their better security in the tools.

The diamond grains can be of ordinary (O), higher (П), and superhigh (В) strength. The corresponding grades of synthetic diamonds are designated as АСО, АСП, АСВ.

In the USSR, the diamond grain sizes are classified into powders (with letter А) and micropowders (with letters АМ). The designations of grain size of synthetic diamond powders include also the letter С (for instance, АС16, АСМ40). The designations for grain size of natural diamond powders are given in Table 4.

The tool makers extensively use diamond wheels for grinding, sharpening, and finishing the parts of hard alloys and hardened steels. Grinding by means of diamonds contributes to production of different dies with cemented-carbide tips prolonging, thus, the life of dies by 30 to 120 times as compared to the life of hardened-steel dies.

Table 4

Grain Size of Natural Diamond Powders

Designation	Grain size of main fraction, mm	Designation	Grain size of main fraction, mm	Designation	Grain size of main fraction, mm
A50	630-500	A10	125-100	AM20	20-14
A40	500-400	A8	100-80	AM14	14-10
A32	400-315	A7	80-63	AM10	10-7
A25	315-250	A6	63-50	AM7	7-5
A20	250-200	A5	50-40	AM5	5-3
A16	200-160	AM40	40-28	AM3	3-1
A12	160-125	AM28	28-20	AM1	1 or finer

Finishing is performed by diamond pastes applied to laps. The most efficient are diamond pastes consisting of 30 to 40 weight per cent of diamond powder and 70 to 60 per cent of olive or castor oil.

Ready-made diamond pastes are available in twelve grain sizes which are conventionally classified into 4 groups: coarse, medium, fine, and very fine. The pastes are packed in wraps of different colours for their easy distinguishing. The pastes themselves are made of light colour so that we can judge of the stock removed by the darkening of the paste.

The weight content of diamond powder in the paste is referred to as concentration. The concentration depends upon the grain size of powder and falls into 3 groups: normal — H (for instance, АСП14Н), higher — П (for instance. АСП10П), and superhigh — В (for instance, АСП7В).

The higher the grain size of diamond powder and the harder the work. the higher should be the concentration of diamond in the paste.

The diamond pastes are available in tubes of 20. 40 and 80 grams.

Cubic boron nitride, also known as elbor or borozon, a recent addition to existing abrasives obtained synthetically, is available in the form of fine cube-shaped crystals of dark-brown colour up to 0.5 millimetres in size. This material is made by synthesizing the boron nitride under high pressure and temperature on hydraulic presses in special chambers.

Cubic boron nitride is almost as hard as diamond (up to 100 gigapascals to Vickers) while its abrasive power in grinding steel is higher than that of diamonds; very little or no adhesion to steel; lower heat conductivity than that in diamonds which makes it heat up rapidly to a high temperature but its heat resistance is 1.5-2 times high as that of diamond (up to 1300-1500°C). The industry produces cubic boron nitride as grains, powders, and micropowders for making grinding wheels and pastes. It is used for treatment of hard alloys, difficult-to-treat grades of steel, especially where strict requirements are extended to the accuracy of size.

The grinding tools from cubic boron nitride are made with ceramic, cermet or organic bonding agents. The powders are made according to the classification approved for grain size of synthetic diamonds. The concentration of pastes is usually 8 per cent.

When dealing with iron-based alloys and hardened steels the life of a tool is 4-5 times as high as that of a diamond tool.

Chapter 4

Hot Processing and Treatment of Tool Steel

4.1. Hardness Tests

Tool steels are tested for their hardness in the as-delivered state and after heat treatment.

The manufacturing iron-and-steel plant denotes the grade of steel and warrants its chemical compositions.

The grade is designated by stamping the pieces of steel, attaching a label, or painting the ends in conventional colour. If the grade of steel is not known, a sample should be sent to the laboratory for analysis.

The hardness of steel is also determined by laboratory tests but there are also instruments which allow this determination right in a workshop.

All 100 per cent of the parts of heat-treated dies, moulds, and jigs and fixtures are to be tested. The test includes cleaning of varnish and scales, visual inspection for cracks and surface defects, measurement of increment or shrinkage, determination of curvature (warping). The steel intended for critical parts is subjected to magnetic and luminescent flaw detection; the hardness is determined by testing with the aid of instruments.

The cracks on the surface are easily detected by inspection. The cracks are of different nature and dependent on faults in heat treatment of metals.

For instance, deep longitudinal cracks are due to the overheating of steel, its sharp cooling (in water below 18°C or in cold oil), ununiform heating or untimely tempering.

Internal arc-shaped cracks result from the insufficient depth of hardening of the work or untimely tempering.

Fine surface cracks are caused by decarbonization of steel heated in a very hot furnace or in the open fire; they

can also arise due to carbonization during annealing, or else due to coarse grinding without coolants.

Metal flakes on the surface may be the result of ununiform heating over the cross section of the work or untimely tempering.

The hardness is determined by one method or another depending on the quantity of metal to be checked, the degree of its supposed hardness (as annealed or hardened), and the state of its surface (rough- or finish-machined).

Brinell hardness. It is determined by forcing a steel hardened ball of 10 millimetres in diameter, under a constant load of 30 kilonewtons (for a specimen of 6 to 3 millimetres thick an 8-millimetre ball is used, for a specimen thinner than 3 millimetres a ball is 2.5 millimetres in diameter). The diameter of the impression is measured with a micrometer microscope. Brinell hardness number (Bhn) is obtained by dividing the load by the spherical surface area of the impression.

The Brinell method is usually applied for non-hardened steels, i.e., when the hardness number is not higher than Bhn 400, the impression diameter being about 3 mm, otherwise the ball may strain or even break. A disadvantage of this method is that the specimen tested invariably bears the impression which is intolerable for some articles.

The Brinell tests are performed with a ball testing machine shown in Fig. 19*a*. The surface of the specimen to be tested should be first filed off or treated by an abrasive wheel to obtain a clean flat area of 1-2 square centimetres, then it is secured on table *2* of the machine. Using handwheel *5* the table is lifted till the treated area of the specimen contacts the steel ball held in spindle *3*. With electric motor *1* switched on, load *4* will be lowered and the spindle indented into the specimen producing an impression in it. The Brinell number is obtained from the impression diameter measured by a micrometer microscope and tables.

Brinell hardness number can also be used for an approximate determination of tensile strength. In carbon steels the relation between the tensile strength and Brinell number is expressed as $\sigma_u = 0.35$ Bhn, but to be on the safe ground one should use special tables.

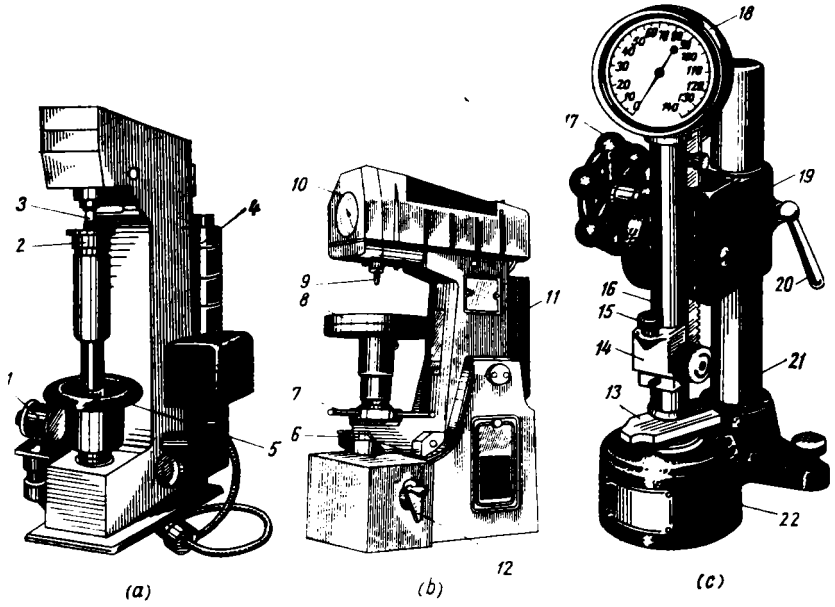

Fig. 19. Hardness-testing machines
(a) Brinell; (b) Rockwell; (c) Shore

Rockwell hardness. This method is applicable for testing metals of any hardness without marring their surfaces. The hardness is determined by the depth of indentation on the specimen surface of a hardened steel ball 1.59 millimetres in diameter or a 120° conical diamond with rounded point, called a brale. The conical diamond is used for testing hard metals (over Bhn 230), the ball for softer ones. The conical diamond is given a load of 150 kilonewtons, the steel ball is loaded with 100 kilonewtons.

For tests of very hard metals and alloys a load of 60 kilonewtons is applied to the conical diamond. In all cases, a minor load of 10 kilonewtons is first applied to avoid inaccuracy due to the state of the specimen surface.

The tests are performed on the machine shown in Fig. 19*b*. The depth of impression is indicated on a dial whose graduations represent the hardness number. The hardness

is expressed in conventional units. The machine is provided with three scales: scale B for a steel ball (R_B) with a range of 25 to 100 units, scale C for a conical diamond (R_C) with a range of 20 to 66 units, and scale A for a conical diamond (R_A) when the hardness is expected to exceed 70 units.

To determine the hardness proceed as follows. Trim off the surface of the specimen and place it on table *8* of the machine, turn handwheel *7* till the specimen contacts indentor *9*. Now turn the handwheel with caution till the point of indicator *10* is opposite the dot division. This means that the conical diamond is indented into the specimen under the load of 10 kilonewtons. Thereafter the moving scale is set to zero, handle *12* is turned to release lever *6*. This done, weights *11* actuated by the levers and the spindle retaining the indentor exert the required force upon it, and the hydraulic damper, built in the machine, provides a smooth loading upon the spindle.

When the load gets stabilized, handle *12* is returned to its initial position and the load is removed. The hardness numbers are read from the indicator dial.

The approximate interrelation between Brinell and Rockwell hardness numbers can be found from the formula Bhn = 9.5-10.5 R_C.

To determine the hardness of surface layers from 0.03 to 3 millimetres thick which are obtained by carburizing, nitriding or other chemical and heat treatment, use is made of a special machine differing from the standard Rockwell tester in that it applies lighter loads. The diamond indentor is impressed first with a minor load of 3 kilonewtons and then with a major load of 15, 30, or 45 kilonewtons.

Vickers hardness. This method is based on the indentation of a square-based diamond pyramid penetrator with an angle between opposite faces of 136° into the trimmed surface of a specimen. Applied load may be varied from 5 to 120 kilonewtons depending upon the thickness of the specimen and the supposed hardness of metal. Vickers hardness number is equal to the load divided by the lateral area of the pyramidal impression. The area is computed from measurements of the diagonals of the square impression.

Shore hardness. This method proceeds from the fact that the hardness of metals is in direct proportion to their elasticity. This method is used when a risk of marring the surface of an article prevents the testers from applying the indentation-based methods.

A special instrument known as a Shore scleroscope (Fig. 19*c*) is used. A diamond-tipped weight or hammer 2.5 grams in mass falls within a glass tube from a pre-determined height, strikes the specimen surface, and rebounds to a certain height depending on the metal hardness. The hardness number is the height of the rebound referred to an arbitrary scale graduated to 140 divisions.

4.2. Forging a Blank

When the ingots of metal are rolled and reduced at the iron-and-steel mill, the steel retains internal stresses, displays ununiform structure, bad distribution of fibres. For a higher density and better structure of metal, the steel blanks intended for critical parts (dies and punches) are subject to forging. Forging consists in repeated (5 to 8 times) upsetting and drawing of the blank which is first heated to a certain temperature.

A part made from a forged blank is twice as strong as the part made from non-forged steel.

When forging die steels (both carbon and alloy) it is necessary to bear in mind that they are of poor heat conductivity, and consequently the close adherence to the prescribed temperature and other conditions of their preliminary and final heating are of paramount importance. Preliminary heating is accomplished in two stages: up to 650°C and then 850°C, the duration corresponding to the cross section of the blank. Then the steel is finally heated up to the temperature prescribed for its grade. Forging done, the blank is allowed to gradually cool off in the furnace under a temperature of 700°C.

The forging should involve the upsetting of the blank by not less than $^1/_3$ its initial thickness. The forged alloy steel blank is gradually cooled off to 250-400°C to avoid burning or directly sent for annealing in the heat-treatment furnace.

4.3. Heat Treatment of Steel

Heat treatment of steel is widely used in production of tools, jigs and fixtures. Steel undergoes heat treatment to improve its structure and mechanical properties.

The basic processes of heat treatment applied to steel are: annealing, normalizing, hardening, and tempering.

Annealing is a softening process of heating steel to a predetermined temperature, holding it at this temperature till the recrystallization is over, and cooling it slowly (in most cases in the furnace). Annealing reduces the hardness of steel, contributes to its workability, and relieves internal stresses. After annealing, steel becomes more ductile and uniform in structure. Depending upon the aim of annealing and the grade of steel it is applied to, the conditions of annealing (the temperature of heating, holding time, and cooling rate) differ within the prescribed limits.

In all types of annealing care should be taken to avoid the overheating and burning of steel.

Overheating of steel is repairable: a coarse-grained structure resulting from overheating can be remedied by another annealing process.

Burning of steel is a defect that cannot be remedied. Here the metal is oxidized on the grain boundaries and the crystalline grains loose the bonds between one another which leads to destruction of the metal piece.

The steels being annealed are usually heated from 30 to 60 minutes for each 25 millimetres of the article thickness. The more carbon and alloying elements in the steel, the slower it should be heated during annealing to avoid high stresses and crack formation.

Isothermal annealing is most applicable to alloy steels. The procedure is to bring the steel being annealed to the proper temperature for full annealing, hold it at this temperature for $^1/_5$ time spent for heating, cool the steel to a temperature of 600-700°C, and then hold it at this new temperature for 30 to 60 minutes. Finally, the steel is cooled in air.

Normalizing is a heat treatment in which steel is heated to a prescribed temperature, held at this temperature, and then cooled in air. Normalizing is applied to low-carbon

steels and may often substitute for annealing. Normalizing ensures fine-grained and homogeneous structure of the steel, makes it better for cutting, relieves cold-hardening from the surface layer of the forged pieces.

Hardening is the most popular heat treatment of steel. Steel is hardened by heating to a prescribed temperature, holding at this temperature, and quenching (rapid cooling) in water, oil, solutions of salts or alkalis. Hardening is applied to impart hardness to steel tooling equipment and to make it more wear resistant. The workpieces are hardened after they have been machined and before grinding and polishing. The quality of hardening depends on proper hardening conditions: the heating temperature, holding time, and cooling rate.

The heating temperature is taken to suit the chemical composition of the steel to be hardened. Heating should be gradual to avoid stresses which cause cracks. Heating to extreme temperatures does not contribute to further hardness, but causes grain growth, decreases strength of metal, reduces plasticity, increases deformation, and makes the metal more liable to cracks.

The heating time is governed by the chemical composition of the steel as well as by the shape and size of the piece treated. For treatment in electrical furnaces the heating period should be within 15-20 minutes per 1 millimetre of the piece cross section, for heating in salt baths this figure should be 0.5 minute per 1 millimetre of the cross section.

The holding period is to be long enough for the entire process of internal changes to fully accomplish. The recommended holding period is about $^1/_4$ the heating time.

The cooling conditions in hardening have much bearing upon the hardening quality. Water quenching results in high hardness, yet full hardening with subsequent water quenching leads to higher internal stresses and strains resulting in crack formation.

When hardening carbon steels, good hardness and low strains can be obtained if the quenching conditions are so selected as to suit the cross section of the steel piece. Small pieces up to 15 millimetres in thickness get partially cooled off in air no matter how quick they are transferred to the cooling medium; this makes it difficult to obtain uniform

and high hardness. In pieces thicker than 30 millimetres (in dia) the hardened surface layer is too thin and changes into soft core abruptly.

A good practice is not to allow the piece being hardened to cool off completely in the active cooling medium (water, solutions of salts and alkalis) but, on the contrary, to apply slower cooling in air or dry sand after the piece has already been cooled off down to 300°C. This makes structural strains more uniform while retaining the hardness obtained.

The ability of steel to harden to a definite depth is called *hardenability*. Depending upon the depth of the hardened layer, the parts can be said full or shallow hardened. The full hardening with continuous quenching in oil is applied to alloy tool steels. Carbon tool steels do not lend themselves to full hardening, their hardening depth being within 10-12 millimetres only. This property of carbon steels is used when hard surface and soft impact-resistant core of a part are important. For the same aim an occasional use is made of so-called *broken hardening*. This means that steel is rapidly quenched in two different cooling liquids in succession. The first liquid is usually a solution of salts, and then the piece is quickly transferred to a bath of oil heated up to a temperature of 40°C. The advantage of this procedure is that it relieves temperature stresses and, consequently, cracks and warps. Besides it yields a good combination of ductility and hardness. The broken hardening is most frequently employed for thin die parts (up to 10 millimetres in cross section) made of carbon steels and for thicker parts (up to 30 millimetres in cross section) made of alloy steels.

The most intensive cooling action is displayed by cold water since the liberated heat, in this case, not only heats water but also turns it to vapour. The quenching power of water is increased by adding salts or alkalis to it. Introduction of lime reduces the rate of heat liberation and smoothes the quenching. Higher temperatures of water or oil will also reduce the quenching rate and weaken the hardening effect produced by the liquids, hence the importance of maintaining constant temperature of the quenching liquid. This is why quenching is carried out in flowing water or in baths where the liquid is cooled by coils with cold flowing water.

Change in the volume of parts and defects due to hardening. Carbon tool steels increase in volume due to hardening, the extent of the increase being in proportion to the carbon content and the degree of heating: the more carbon present in the steel and the higher heating temperature prior to hardening, the more intensive growth in the volume of the steel. The most usual case is that the external cross section of a part grows while the diameter (or cross section) of the hole diminishes. In slender round parts the diameter invariably grows while the length decreases.

Changes in the volume of all hardened parts cause considerable internal stresses leading to cracks when the articles are hardened, occasionally they can even be torn to pieces. Stresses can be especially severe in large-size parts, in parts of an intricate shape, or when they are quenched too rapidly.

The largest changes in the volume of carbon steel occur by the end of its quenching, approximately during the conclusive 400-200°C. It is under those temperatures, i.e., at the very end of the hardening, that large dies and punches are often torn to pieces. If the quenching within this temperature range is too extensive, the articles are more vulnerable to crack. Slower cooling within this temperature range provides for that the local changes in the volume of the article will be gradual and more uniform, high internal stresses will be avoided, and as a result there will be no cracks in the article.

Changes in the volume of metal caused by hardening are taken into account when prescribing the allowances for final grinding and finishing of dies and punches. This is especially relevant to the ports in dies which need finishing after heat treatment.

Extreme heating of carbon steels not only leads to considerable changes in the volume, but also increases their brittleness which, in turn, causes fine cracks in sharp edges of articles and the latter may crush off. Overheating of an article for a long time may lead to a partial burning of carbon from its external side and the article will not be hardened as required. This can be remedied by carburizing, i.e., impregnating the surface layer, and especially the sharp edges, with carbon. Only after this the article can be given conventional hardening.

The hardening defects may arise due to cuts and scratches left by cutting tools on the surface of machined articles to be hardened. This is a cause of crack formation in such places. Warping results from ununiform cooling of individual parts in the article.

Tempering. All hardened articles undergo subsequent tempering which stabilizes the structure and, thus, the properties of the metal. The purpose of tempering is also to relieve the stresses due to hardening. Tempering is a process in which hardened steel is heated to a definite temperature (depending upon the type of tempering and the future service of the article), held at this temperature, and then cooled at different rates. Tempering immediately follows hardening before the hardened metal has been destroyed by hardening stresses.

There are three types of tempering: low-temperature tempering, medium-temperature tempering, and high-temperature tempering.

Low-temperature tempering relieves the internal stresses without essentially changing the structure of the steel and reducing its hardness. The articles subject to this kind of treatment are slowly heated to a temperature of 150-200°C and cooled at the same rate.

Medium-temperature tempering, which involves heating the hardened article to 250-450°C, is aimed at relieving the stresses and increasing the ductility. Such tempering leads to a partial reduction in the hardness of the metal but its mechanical properties improve.

High-temperature tempering is performed within a range from 500° to 650°C. At these temperatures the internal stresses are almost completely eliminated while the crystalline structure is refined. The metal softens considerably but its ductility grows.

A double heat treatment involving the hardening of steel and subsequent high-temperature tempering is known as *toughening*.

In tempering it is essential to obtain the assigned temperature and to observe the holding period under it. The process lasts from 30 to 60 minutes. The rate of cooling the tempered metal is of no essential consequence. A rapid quenching in water or in oil bath is applied only for some gra-

des of alloy steel which display temper brittleness (poor resilience after tempering).

Aging is a process of relieving the stresses which are due to machining. The process consists of slow he ting of metal up to moderate temperatures (120-160°C) and holding it under such temperatures.

Aging is mostly applicable to rough-ground metal parts which are intended for manufacture of machine components subject to strains (slim punches, die plates).

Temperature control. In heat treatment the heating temperature is determined by means of special instruments, such as pyrometers and electric thermometers (thermocouples). In shop practice, when no instruments are available, the heating temperature can be determined by eye according to *heat colours* (for hardening) and *temper colours* (for tempering) which appear on the bright-trimmed surface of a hardened part.

The heat colours and temper colours together with the temperatures that approximately correspond to them are shown in Fig. 20.

4.4. Heat Treatment of Punches and Dies

Different types of heat treatment are widely used in the manufacture of tool equipment.

No press tool, no matter what its purpose is, can be made obviating heat treatment of its components. This, however, does not imply that the main components of a press tool—punches and dies—must be, say, hardened. For punching small batches of parts out of soft metal sheets (soft steel, brass, aluminium) there is no need in hardening both the punch and the die. It proves sufficient if only the die is adequately hardened.

The punch can be made much softer than the die so that the play likely to occur does not result in the punch marring the hardened die. The punch is fitted up to the die by pressing through, when the punch gets blunt it can be easily remedied. The less the depth of the punch entering the die, which is a factor of the thickness of metal being stamped, the easier the remedying.

Thus, for punching any soft material the die can be hardened and the punch left green or moderately hardened.

For hot punching both the die and the punch are hardened to an equal degree.

In making press tools for punching the parts of precise external dimensions the punch is hardened since it is its duty to secure precision in parts, whereas the die can be softer than the punch. Under these conditions the punch will preserve a shape over the entire hardened section for a long time. Should its edges get slightly blunt, they can be easily-sharpened from the faces. The worn soft die can also be easily repaired by caulking its cutting portion.

The larger the press tool component and the more intricate its shape, the more vulnerable it is during hardening and, consequently, liable to develop cracks, warps, and size distortions.

To preclude cracks and warps, all the holes which are not to be hardened should be closely stopped up with a mixture of clay and asbestos or densely packed up with wet asbestos.

The precision components of small-size press tools are heated in closed steel boxes filled in with charcoal to save the surface of components against scaling and to obtain a uniform heating. The press tool components are placed in a box with their faces down on the charcoal.

All the punches and dies, no matter what steel they are made from, should be tempered, but the degree of tempering is selected to suit the grade of steel and the working purpose of the tool.

Small-size components are most conveniently tempered in a pan with hot sand.

For cooling off the press tool components different methods are used depending on their size and shape. For instance, low thin punches are dipped into water or oil baths, held vertically and with the narrow rib down; thicker punches, as well as round ones, must be dipped with their cutting edges entering the bath first.

More intricate and harder components call for slower immersion into a warmer liquid. Thus, the dies of intricate shape made from hard steel should be hardened in water heated to 40-50°C or in oil baths heated to 60°C.

When dealing with large round dies having large ports, the working surface alone should be hardened. For this purpose use is made of hardening by spraying with the aid of a pipe whose brazed end has fine holes.

Bulky piercing punches are heated on the hearth of a muffle or electric furnace and held vertically in water to cool them off. They are better tempered when hardened, i.e., quenching should not be complete but so as to secure internal heat for heating the working part of the punch to the required tempering temperature. If such tempering method is impossible, then a sand bath should be resorted to and heating started from the shank.

The punches of simple shape, when heated for hardening, are first quenched in water. In this process not the entire punch is quenched but only the portion of 15-20 millimetres from the blade over its height. As soon as the blade darkens, the punches are quickly transferred from water into an oil bath. This method allows the core and the shank of the punch to be made very ductile while retaining adequate hardness of its working portion.

To prevent slender punches from frequent breakage, they should be hardened all over their length at once without leaving any sharp transitions from the hardened working portion to the green shank. The shank section is then tempered (heated in sand, hot oil or a salt bath) to obtain higher elasticity in the punch.

The punches liable to warping should be quenched in a vertical position while dipping into the liquid as slowly as possible. If the punch shape contains changes from one section to another, an interval not less than 1 or 2 seconds should be observed before passing over to each subsequent section, the duration of the interval depending upon the size of the punch. This helps avoiding warps and cracks.

Short bulky punches usually develop cracks when hardened. This can be precluded by annealing the punches, prior to hardening, at a temperature of 760-780°C; besides, the punches being hardened should be heated as uniformly and slowly as possible. The best method of cooling the punches is by spraying water over them from a sprayer. The hardened punches should be tempered in an electric furnace or in a sand bath.

The dies and punches made from alloy tool steels are subject to full (through) tempering while continuously quenching them in an oil bath.

Carbon steels do not lend themselves to through hardening (they can be hardened to the depth of mere 10-12 millimetres), this being used when the hard surface of a part with a soft impact-resistant core is required. In some cases this aim can be achieved by *broken hardening* which is a rapid subsequent quenching in two dissimilar cooling media. The first medium is solutions of salts and the second, oil heated up to a temperature of 40°C.

The advantage of this method consists in relieving thermal stresses and, consequently, precluding crack formation, shrinkage and warping, besides it results in a favourable combination of high ductility and strength. The broken hardening is applied to thin parts of press tools made of carbon steels and to thicker parts made of alloy steels.

4.5. Case Hardening of Steel

The purpose of case hardening of steel is to change the chemical composition of its surface layer in ready articles with an aim of increasing the surface hardness of steel, its corrosion resistance, etc.

There exist various methods of case hardening allowing the saturation of the surface of steel with carbon, nitrogen, chromium, and boron. Carbon and nitrogen form such chemical compounds as iron carbides and nitrides. Chromium and boron penetrate to the surface layers of metal to form complex carbides of the hardness exceeding that of iron carbides.

Case hardening involves heating of steel, holding it at the prescribed temperature, and quenching. In production of tool equipment the following types of case hardening are applied: carburizing, nitriding, calorizing, and diffusion chromizing.

Carburizing, a time-honoured method for increasing the surface hardness of steel, consists in saturating low-carbon steel (carbon content 0.2-0.4 per cent) with carbon. The method is based on the ability of iron to dissolve carbon absorbing as much as 0.9-1.2 per cent carbon. The steel being

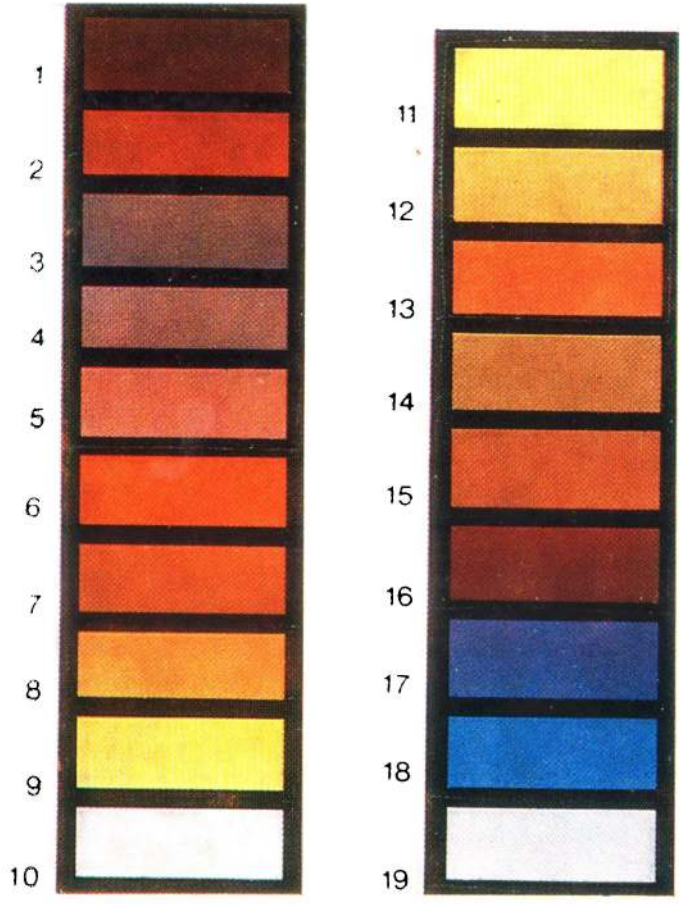

Fig. 20. Heat colours (*a*) and temper colours (*b*) in heating carbon steel

red, visible in the dark (550-580°C); *2*—red, visible in the sunlight (580-650°C); *3*—dull cherry-red (650-730°C); *4*—cherry-red (730-880°C); *5*—bright cherry-red (770-830°C); *6*—dark orange (830-900°C); *7*—orange (900-1050°C); *8*—orange-lemon (1050-1150°C); *9*—lemon (1150-1250°C); *10*—white (1250-1300°C); *11*—light straw (220°C); *12*—straw-yellow (230°C); *13*—deep straw-yellow (240°C); *14*—yellow brown (255°C); *15*—red-brown (280°C); *16*—dark purple (285°C); *17*—dark blue (295-310°C); *18*—light blue (315-325°C); *19*—grey (330°C)

carburized is heated to over 910°C and made contact the carbon-containing substances, the latter being known as *carburizers.*

Carburizing can be accomplished by means of solid, gas, and liquid carburizers. Solid carburizers are most widely used. The parts to be carburized are packed in a box made from heat-resistant steel, then a layer of crushed charcoal with additives is placed over them, accelerating the process of carburizing (for instance, 75 per cent coal, 15 per cent barium carbonate, 5 per cent calcium carbonate, 1 per cent sodium carbonate, and 4 per cent masout). The carburizer should be rammed. The parts placed in the box are spaced 25-40 millimetres from one another. The carburizing box is tightly covered closing the joints with fire clay. When the clay dries, the box is charged into a furnace heated to 700°C, then the temperature in the furnace is raised to 920-940°C and the box is held at this temperature for a period calculated on the basis of the rate of carbon penetration into steel (0.1 millimetre per hour). The carburizing depth reaches, thus, 3 millimetres.

At the time when the parts are arranged in the box, the test bars are placed in the box too, these being of the same material as the parts. Such bars are sometimes called "witnesses" since they are used to determine the depth of carburizing.

Liquid carburizing is accomplished in a bath of a molten salt of cyanide. This method is particularly suitable for strengthening the surface layer of small steel products.

Gas carburizing is accomplished in special furnaces by saturating steel with carbon liberating from gaseous compounds, such as CH_4, CO, etc. Liquid and gas carburizing processes are more efficient than that using solid carburizers, but they are not very popular in production of tooling equipment since they cannot secure adequate carburizing depth, besides they are suitable only for steels containing not more than 0.2 per cent carbon.

The carburized parts are hardened by one of the following methods: (a) hardening of red-hot parts taken directly from the carburizing box; (b) cooling parts off in the box, heating them again in the furnace up to 760-780°C, and quenching them in water or oil; (c) combined double heating

and hardening of parts cooled off in the box down to 600-650°C, their cooling in the furnace, another heating up to 900°C with subsequent quenching in oil, still another heating up to 780°C, and quenching in water.

When making press tools the following parts are carburized: guide posts, guide bushes, holders for quick-replaceable punches and other parts made of steel grades 15, 20, and 30.

Nitriding is the process of saturating the surface of steel with nitrogen at a temperature ranging from 480 to 620°C for 10 to 60 hours. The nitrided case, usually from 0.5 to 0.8 millimetre deep, is very strong; it is retained even when the metal is heated up to 550°C. The nitrided parts require no further heat treatment, they will never deform.

Nitriding is usually applied to the working parts of drawing, bending and forming dies made of alloy steels containing chromium, molybdenum, vanadium which readily associate with nitrogen to form very hard chemical compounds. The parts to be nitrided are first hardened to obtain a hard cushion.

Nitriding is disadvantageous in that the nitrided steel becomes liable to increase in size as a result of heat treatment which is accounted for by the growth of the crystal volume when the steel is saturated with nitrogen.

To combat deformation, nitriding should be carried out at as low a temperature as possible and the case saturated with nitrogen should be reasonably shallow.

In the manufacture of tooling equipment, nitriding is applied to critical parts of testing and measuring tools subject to friction wear.

Calorizing, the surface impregnation of steel parts with aluminium, is done to increase the life of parts in tooling equipment, which work at elevated temperatures. Calorizing makes steel refractory. This method is applied when making injection moulds.

Diffusion chromizing is a process in which the surface of steel parts is impregnated with chromium. The purpose of this method is to increase hardness, wear, and corrosion resistance of critical parts in injection moulds.

Chapter 5

Measuring and Marking-Off Techniques

5.1. Technical Measurements and Geometrical Accuracy

Producers of tools, jigs and fixtures should measure the following parameters: linear dimensions—length, width, thickness, diameter, depth, angles; departures from correct shape and surface, i.e., departures from straightness, parallelism, perpendicularity, flatness, roundness, cylindricity, curvature prescribed by the drawing.

Depending on the requirements extended to the accuracy of products, different methods and means of measurement are employed. In practice, every measurement, no matter how carefully it is taken, involves errors and the value obtained is an approximate description of what is measured.

The measurement errors may be caused by:

faults of measuring tools or instruments, or their inaccurate mounting;

inaccurate mounting of the work to be measured;

variations in efforts exerted when applying the measuring tool to the work;

inaccurate inspection due to inadequate skill of workmen;

difference in temperatures of the work and the measuring tool (20°C is assumed to be normal temperature for measuring purposes);

poor working condition of the measuring tool.

In most cases the toolmakers are concerned with precision in the range from tenth to thousandth fractions of a millimetre. The measuring tools produced by the industry are designed to meet these requirements.

For better accuracy, measuring can be repeated and, then, the arithmetic mean of several measurements determined.

A rapid progress of technology and exact requirements extended to the precision of tooling equipment have also brought about rigorous requirements to measuring tools which, in turn, makes it obligatory for workmen to know well the design and operation of measuring tools and to be experienced in measuring techniques.

In the manufacture of parts not only departures from the assigned dimensions are likely to occur, but also deviations from the correct geometrical shape of a part, as well as from the location of surfaces with respect to one another. Let us consider the departures most frequent in the practice of a tool fitter.

The following designation is accepted for describing the inaccurate geometrical shape of parts: ovality (out-of-roundness), facetting, taper, barrel, bow, curvature, radial run-out, end run-out, convexity, concavity.

Ovality is such a departure from the true cylindrical shape wherein the section diameters measured in mutually perpendicular directions are not equal. The difference between the maximum and minimum section diameters is assumed to be the value of ovality (Fig. 21*a*).

Facetting is such a departure from the true cylindrical shape wherein the real profile is a multi-edged figure. The maximum distance from the circumference circumscribed round the section figure to the contour of the real profile is assumed to be the value of facetting (Fig. 21*b*).

Taper is a departure from the correct geometrical shape wherein the generatrices are straight but not parallel. The difference in the diameters of two cross sections spaced from each other at a certain distance is assumed to be the value of taper (Fig. 21*c*).

Barrel is out-of-straightness of generatrices wherein the diameters increase from the sides towards the middle of the section (Fig. 21*d*).

Bow is out-of-straightness of generatrices wherein diameters decrease from the sides to the middle of the section (Fig. 21*e*).

Curvature is a departure from the true cylindrical shape wherein the geometrical point of the centres of cross sections in the cylindrical surface is out of the straight line (Fig. 21*f*).

Radial run-out results from the shift of the centre of the section relative to the part axis and from out-of-roundness of the section itself (ovality, facetting). The radial run-out is determined as the difference between the maximum and the minimum distances of the points of the real surface to the part's axis of rotation in the section perpendicular to this axis (Fig. 21*g*, from the left).

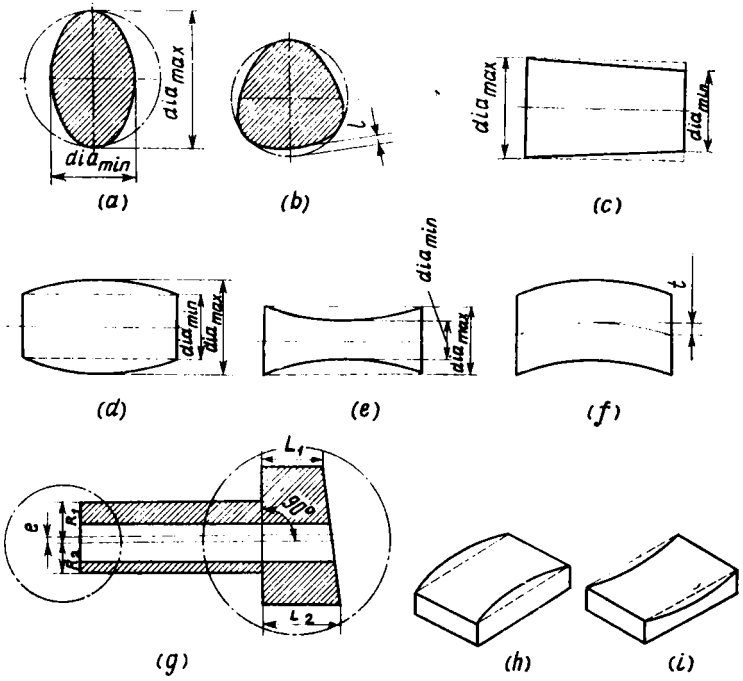

Fig. 21. Departures from true geometrical shape and correct mutual positions

(*a*) ovality; (*b*) facetting; (*c*) taper; (*d*) barrel; (*e*) bow; (*f*) curvature of axis; (*g*) run-out; (*h*) convexity; (*i*) concavity; *l*—value of facetting; *t*—value of curvature; *e*—hole eccentricity

End run-out is a result of non-perpendicularity of the face with respect to the basis axis and of the departure of the face shape along the line of measurement. The end run-out is determined as the difference between the maximum and minimum distances of the points on the real face located on the circumference of the assigned diameter and the plane perpendicular to the part's axis of rotation (Fig. 21*g*, from the right). If the diameter for measuring the run-out is not pre-determined, the end run-out is measured at the maximum diameter of the face.

Non-parallelism (departure from parallelism between the surfaces) varies at different sections. The difference between the maximum and minimum distances of the planes within the assigned area over the length is assumed to be the value of non-parallelism.

Non-perpendicularity (departure from perpendicularity) of the planes, the axes or the axis and the plane is a deviation of the angle between the planes, the axes, or between the axis and the plane from an angle of 90°. Non-perpendicularity is expressed in linear units over the assigned length or in degrees.

Departure from the correct geometrical shape and mutual position of the surfaces can also display itself as *convexity* (Fig. 21*h*) or *concavity* (Fig. 21*i*).

5.2. Surface Roughness and Its Estimation

Surface roughness is surface microirregularities measured within small areas and estimated in the terms of accuracy classes of surface finish.

The USSR State Standard establishes 14 classes of surface finish (Table 5) designated in the drawings and other technical documents by a symbol of ∇ followed by figures denoting the class of accuracy. In this notation higher classes correspond to lesser permissible values of roughness and, consequently, to better surface finish.

Roughness of machined surfaces is normally dependent upon the machining accuracy, i.e., higher grades of machining accuracy spell higher classes of surface finish. In some cases the surfaces of parts are machined to obtain better surface finish with an aim of imparting good appearance of products; another reason may consist in preparing the surface for electroplating.

Surface roughness is specified by referring to one of the following parameters (Fig. 22*a*):

(a) arithmetic mean deviation of profile R_a equal to the average value of the distances ($y_1, y_2, \ldots y_n$) between the points of the measured profile and its centreline m (the y increments being added without regard to sign);

(b) height of microirregularities R_z, which is the average distance between the five highest peaks and the five

Table 5

Surface Finish Classes and Numerical Values of Roughness

Surface finish class	Arithmetic mean deviation of profile R_a, microns (maximum)	Height of roughness R_z, microns (maximum)	l, mm	Surface finish class	Arithmetic mean deviation of profile R_a, microns (maximum)	Height or roughness R_z, microns (maximum)	l, mm
∇1	80	320	8	∇8	0.63	3.2	0.8
∇2	40	160	8	∇9	0.32	1.6	0.25
∇3	20	80	8	∇10	0.16	0.8	0.25
∇4	10	40	2.5	∇11	0.08	0.4	0.25
∇5	5	20	2.5	∇12	0.04	0.2	0.25
∇6	2.5	10	0.8	∇13	0.02	0.1	0.08
∇7	1.25	6.3	0.8	∇14	0.01	0.05	0.08

Notes: (1) Numerical values of surface roughness are related with normal section of geometrical surface.
(2) The basic scale for Classes 6-12 is that of R_a, for Classes 1-5 and 13, 14 the basic scale is that of R_z.

lowest values within the base length l measured from the line parallel to the centreline ($0 - x$).

Mathematically, R_a and R_z are expressed as:

$$R_a = \frac{y_1 + y_2 + \dots y_n}{n} \text{ microns}$$

$$R_z = \frac{(h_1 + h_3 + \dots h_9) - (h_2 + h_4 + \dots h_{10})}{5} \text{ microns}$$

The centreline of profile m follows the nominal profile and divides it so that within the base length l the areas on the both sides of this line of profile m are equal:

$$F_1 = F_3 + \dots\dots F_{(n-1)} = F_2 + F + \dots\dots F_n$$

The Standard establishes a number of values of the base length l as applied to surface finish classes, these are employed in the practice of measuring surface roughness. The table includes the surface-finish classes and the corresponding values of R_a, R_z, and l.

Surface finish is measured by special tools and instruments: profilographs, profilometers, microinterferometers,

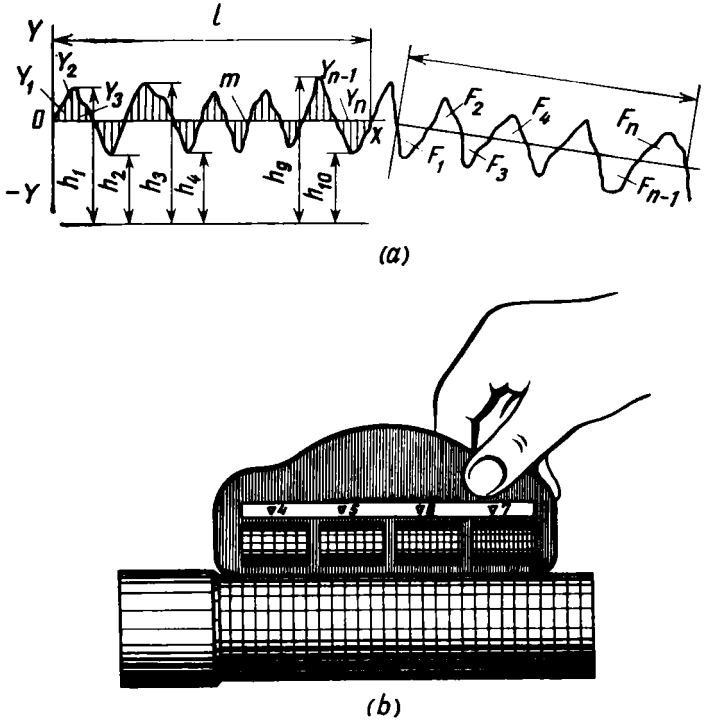

Fig. 22. Micro-roughness of machined surfaces (*a*) and the method for estimating class of surface finish using a sample (*b*)

comparison microscopes, etc. As to the method in which they evaluate surface finish, the instruments may be classified into (1) contact (including those with magnifying glass) and (2) contactless (optical).

The operating principle of the contact-type instruments essentially is as follows: a diamond or steel needle travels over the surface being measured, the vertical displacements of the needle which follow the height of microirregularities are amplified electrically, optically or mechanically and recorded by a counter.

The contactless instruments employ the optical principle.

They are more accurate but do not record the observed deviations automatically.

In shop practice, the class of the surface finish can be specified by its reference to special samples which are a set of steel plates finished to a certain class. The surface whose finish is to be estimated is visually compared to the sample surface and the class of finish is thus determined (see Fig. 22*b*).

5.3. Tolerances and Fits. Classes of Accuracy

No machine component or even a part of it can be made to an absolute accuracy prescribed by the drawing, hence a concept of tolerance, a permissible variation in manufacturing accuracy.

The limitations of accuracy are accounted for by different errors which cause departures from the assigned size and shape. The sources for departures are numerous, the main ones being the following: inadequate precision of equipment used for machining parts; inaccuracy of tools, jigs and fixtures; measurement errors; heterogeneity of physical properties of the material the parts are made from; elastic deformations; variations in size due to changes in temperature, etc.

Taking into account possible errors the designers supply the drawings with two sizes: the maximum limit and the minimum limit instead of one nominal size.

The difference between the maximum and minimum limits is called *tolerance.*

Nominal size is the basic size of the part (or two mating parts) used for the purpose of identifying the deviations.

Actual size is the size found by direct measurement taken to the highest possible accuracy.

Limits of sizes are those between which an actual size may vary.

Upper deviation is the difference between the maximum limit and the nominal size.

Lower deviation is the difference between the minimum limit and the nominal size.

In the example shown in Fig. 23*a* the nominal size of the cylindrical surface of the shaft is 50 millimetres. The

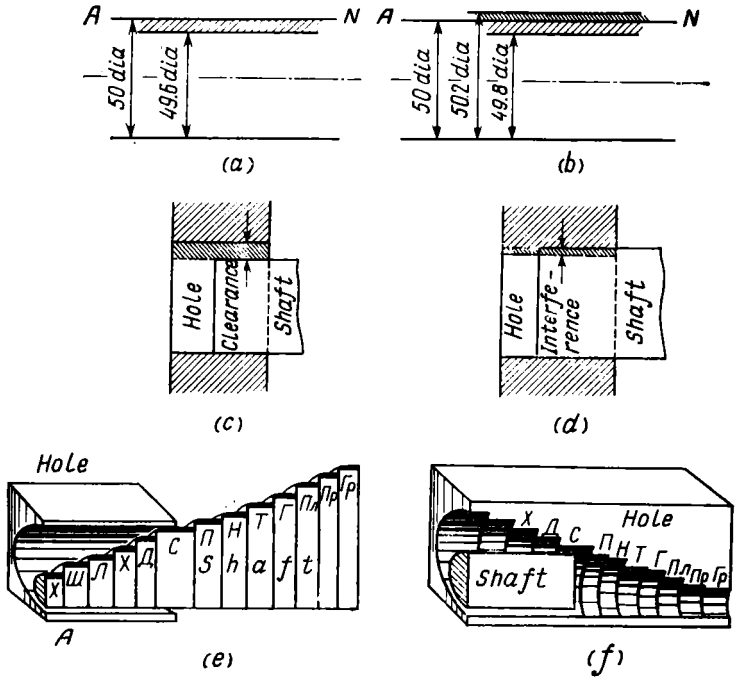

Fig. 23. Graphical representation of machining tolerances (*a* and *b*), clearance and interference (*c* and *d*), fits in the basic-hole system and basic-shaft system (*e* and *f*)

maximum limit coincides with the nominal size, and the minimum limit is 49.6 millimetres. Thus, the upper deviation is 0 and the lower deviation is —0.4 millimetres. The tolerance is 0—(—0.4) = 0.4 millimetres.

Figure 23*b* illustrates another example. The maximum limit 50.2 millimetres does not coincide with the nominal size which is 50 millimetres. The minimum limit is 49.8 millimetres. Thus, the upper deviation is +0.2 millimetres, and the lower deviation is —0.2 millimetres. The tolerance is 50.2 — 49.8 = 0.4 millimetres.

In graphical representation of tolerances the line *A-N* corresponding to the nominal size is called a *base line* and

the hatched section corresponding to the value of tolerance is called a *tolerance zone.*

In dealing with two mating parts, one of which enters the other, one can distinguish the *enveloped* and the *enveloping* surfaces. The enveloped surface of the joint is conventionally referred to as a shaft and the enveloping one is a hole. These terms are applied not only to cylindrical but also to other enveloped and enveloping surfaces. The corresponding sizes are known as a shaft diameter and a hole diameter.

The positive difference between the diameters of the shaft and the hole, allowing relative movement between the parts, is called a *clearance.*

The difference between the minimum limit of the shaft and the maximum limit of the hole is the *maximum clearance* while the difference between the maximum limit of the shaft and the minimum limit of the hole is the *minimum clearance.*

Table 6

Fits and Their Drawing Symbols

Groups of fits	Fits	Drawing symbols
Interference fits	Heavy drive 3	Пр3
	Heavy drive 2	Пр2
	Heavy drive 1	Пр1
	Shrink	Гр
	Heavy drive	Пр
	Light drive	Пл
Transition fits	Force	Г
	Tight	Т
	Wringing	Н
	Push	П
Clearance fits	Slide	С
	Easy slide	Д
	Running	Х
	Slack running	Л
	Loose running	Ш
	Running	ТХ

The negative difference between the diameters of the hole and the shaft prior to assembling operation is called an *interference*. The joint with an interference is a fixed one. The *maximum interference* is the negative difference between the maximum limit size of the shaft and the minimum limit size of the hole. The *minimum interference* is the negative difference between the minimum limit size of the shaft and the maximum limit size of the hole. Figure 23 (*c* and *d*) is a graphical representation of a joint with a clearance and an interference.

The nature of the association between two parts where one is inserted into the other with a certain degree of tightness or looseness is known as a *fit*.

Depending on how the parts mate, fits can provide for different degrees of freedom of the parts movement with respect to one another.

The machine builders use a number of fits both with interference and clearance; use is also made of transition fits wherein, depending upon the actual sizes of the mating parts, either an interference or a clearance may result. Table 6 presents the types of fits and their notation.*

Interference (fixed) fits of Пр3, Пр2 and Гр groups are mainly intended for assembling the parts in which the hole is pre-heated or the shaft is pre-cooled to low temperatures, those of Пр1, Пр and Пл for cold assembling with the aid of press.

Transition fits are used in fixed joints assisted by screws, bolts, pins, keys and other fastenings. Such fits are mainly used as fits for centering the mating parts.

Clearance fits are intended for the joints where a clearance is required.

A schematic arrangement of fits in the basic-shaft system and the basic-hole system will be found in Fig. 23*e* and *f*.

For correct assignment of permissible deviations when

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* English names, given here to the fits in the USSR standard, have been selected to broadly characterize their properties. It is not to be inferred that they coincide in tolerances with fits of the same name employed in the UK or in the United States (Editor).

selecting the fits, a tolerance system has been worked out which presents reasonable combinations of tolerances and fits and is subdivided (1) according to the basis, into the basic-hole (H.B.S.) and basic-shaft (S.B.S.); (2) according to the size of tolerances, into several classes of manufacturing accuracy; (3) according to the size of clearances or interferences, into a number of fit types.

The basic-hole system is the system in which the hole limits are constant for all fits of the same class of accuracy and for the same nominal size, the various types of fits being obtained by suitably varying the limits of the shaft (see Fig. 23*e*). In the drawings, the letter A and the numeral denoting the class of accuracy will be found next to the designation of the nominal size. The numerical values of deviations from the nominal size can be taken from the tables of tolerances and fits.

Let us consider an example: $\varnothing\ 25A_3$ stands to show that the hole should be machined according to the basic-hole system with Class 3 accuracy. The numerical values of these deviations will be found as: the upper deviation +45 microns, and the lower deviation 0. The notation on the drawing can be presented as: $\varnothing\ 25 + 0.045$.

The notation of $\varnothing\ 25X_3$ serves to designate: the shaft of 25 millimetres in diameter, Class 3 accuracy, running fit in basic-hole system. The numerical values: $\varnothing\ 25\ ^{-0.025}_{-0.085}$ (deviations from the nominal size: —25 and —85 microns).

The basic-shaft system is the system in which the shaft limits are constant for all fits of the same class of accuracy and for the same nominal size, the various types of fits being obtained by varying the hole limits. The notation of tolerances in the basic-shaft system is similar to that in the basic-hole system. The deviations in the basic part, i.e., the shaft, are designated by the letter B with the numeral of accuracy class placed to the right. For instance: $\varnothing\ 5B_3$. In the basic-shaft system, the nominal size *d* is the maximum limit size of the shaft, the various types of fits being obtained by varying the hole diameter.

The two tolerance systems are asymmetrical and limit, i.e., the systems wherein the tolerance zones of the basic parts are arranged on one side from the base line: "to plus"—

for the hole in the basic-hole system and "to minus"—for the shaft in the basic-shaft system.

The basic-hole system finds a wider application at the engineering enterprises, since it involves fewer types and sizes of standardized cutting tools for treating holes. However, in some cases the basic-shaft system cannot be obviated, for instance, when mounting the rolling bearings in the machines.

The engineering industry employs 10 classes of accuracy: 1, 2, 2*a*, 3, 3*a*, 4, 5, 7, 8, and 9. Class 1 is the most precise. Classes 2, 3, and 4 are applied most extensively.

Notation of tolerances in drawings. The usual practice in working drawings is to indicate the deviations by numerical values, while in assembly drawings they are designated by the symbols (letters) assigned to the given fit and adding an index showing the class of accuracy required for the mating parts.

Let it be assumed that a size given in a drawing is $50\ ^{+0.05}_{-0.03}$. It is read as follows: the nominal size of the diameter is 50 millimetres, the maximum limit size of the diameter $50 + 0.05 = 50.05$ millimetres, and the minimum limit size $50 - 0.03 = 49.97$ millimetres.

Sometimes drawings will bear the numerical values of tolerances in addition to the symbols of tolerances, for instance, $27T_1\ (^{-0.004}_{-0.017})$.

In assembly drawings the symbols are indicated as fractions. The letter symbol applying to the hole is indicated above the dimension line, that applying to the shaft is indicated below it, as for instance $50\ \frac{A}{H}$. This means that the association must have a nominal size of 50 millimetres and is to be made to the basic-hole system, to Class 2 accuracy (Class 2 accuracy is conventionally not shown), the shaft is set with a wringing fit.

There may be some cases in the machine-building practice when one mating part is made to one class of accuracy and the other to a different class. For instance, $\varnothing\ 15\ \frac{A_3}{\Pi_4}$. This means that in the association the shaft is made to Class 4 accuracy with the easy slide fit in the basic-hole system, the tolerance of the bush hole is to Class 3 accuracy.

Let us consider one more example: $25 \frac{\Pi 2a}{B_3}$. The given designation means that the association must have a nominal size of 25 millimetres and is to be made to the basic-shaft (B) system, i.e., the shaft is the basic part, while the tolerance on the mating hole provides for a push (П) fit and is made to Class 2*a* accuracy, the shaft being made to Class 3 accuracy.

5.4. Measuring and Inspection Devices

Measuring Tools with Scales and Verniers

These tools are most extensively used in machine-building practice. They find application in measuring external and internal diameters, length, thickness, depth, etc. This class of measuring tools includes calipers, depth gauges, gear tooth gauges, height gauges. The basic part of such tools is a *beam* which is graduated in the main scale divisions. The beam carries a sliding head with a cut-out whose inclined side has a *vernier*, an auxiliary scale.

Depending on the class of work the measuring tools are intended for, the number of divisions on the vernier scale may be 10, 20, and 50. This makes it possible to take readings with an accuracy of 0.1; 0.05; or 0.02 millimetre. With the closely contacting jaws of the measuring tool of 0.1-millimetre reading, the zero line of the vernier coincides with the zero line of the beam, and the tenth line of the vernier with the ninth line of the beam. 9 millimetres of the beam scale coincide therefore with 10 divisions of the vernier, thus each division of the vernier is equal to 0.9 millimetre (Fig. 24*a*).

When the position of the vernier is such that its zero line coincides with the beam zero line, the first division of the vernier will not reach the first division of the beam by 0.1 millimetre, the second by 0.2 millimetre, the third by 0.3 millimetre, and the ninth by 0.9 millimetre. If the sliding head is moved so as the first line of the vernier coincides with the first line of the beam, the clearance between the jaws will be 0.1 millimetre. For example, when the sixth line of the vernier coincides with the sixth line

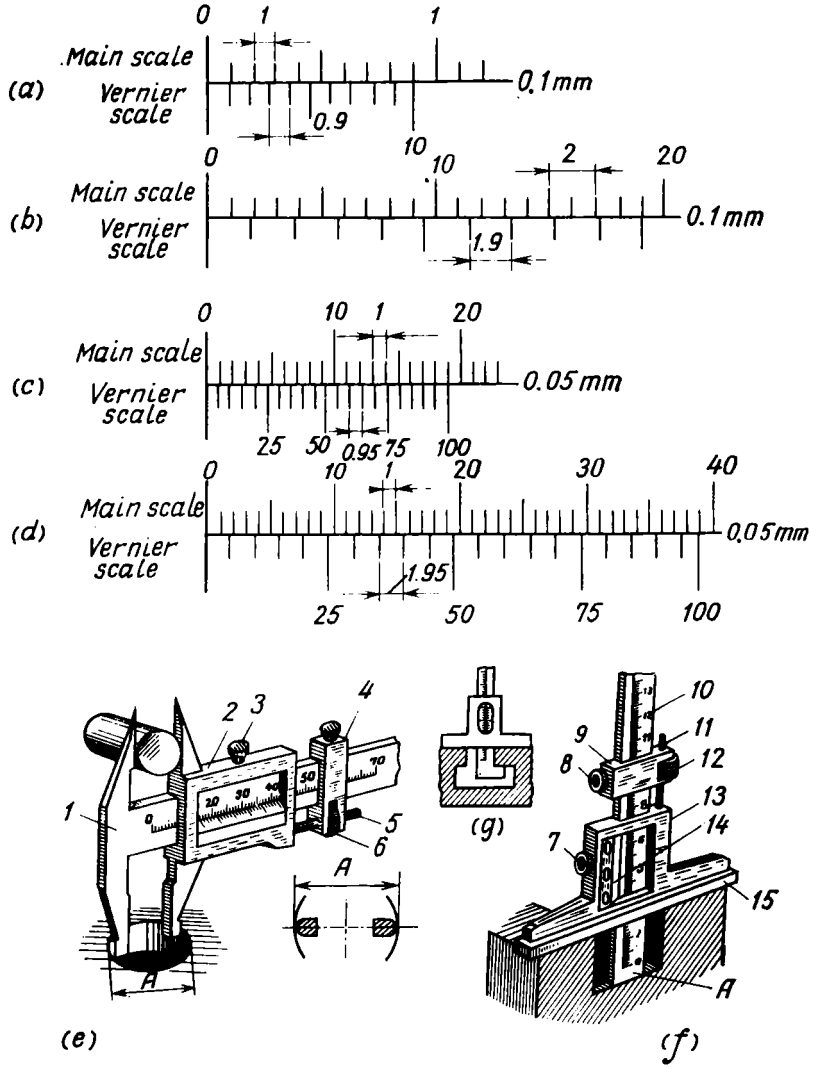


Fig. 24. Measuring tools with scales and verniers

(*a*), (*b*) vernier scales for reading accurate within 0.1 mm; (*c*) scale for reading accurate within 0.05 mm; (*d*) scale with extended vernier for reading accurate within 0,05 mm; (*e*) vernier caliper; (*f*) vernier depth gauge; (g) application of a beam with a bent end; *1*, *10*—beams; *2*, *4*—sliding heads; *3*, *7*, *8*—clamps; *5*—screw; *6*—nut; *9*—slide; *11*—micrometric feed; *12*—nut; *13*—head; *14*—vernier scale; *15*—base

of the beam, the clearance between the jaws will be 0.6 millimetre, etc.

To read the actual size on the measuring tool with a beam, the whole millimetres are read on the beam scale to the zero line of the vernier, and the tenth fractions of a millimetre are read on the vernier by determining which line of the vernier coincides with a line of the beam scale.

In modern measuring tools with beams the vernier scale is provided with larger divisions and is of 19 millimetres in length. This makes the reading more convenient, since each division of the vernier is equal not to 0.9 millimetre but to 1.9 millimetres. This does not violate the principle of determining the size accurate to within 0.1 millimetre (Fig. 24*b*).

In measuring tools with beams accurate to 0.05 millimetre, the vernier scale is equal to 19 millimetres and graduated into 20 divisions. Each vernier division is equal to 19 : 20 = 0.95 millimetre, i.e., shorter than the divisions of the beam scale by 1.00 — 0.95 = 0.05 millimetre (Fig. 24*c*).

In the extended vernier the scale is equal to 39 millimetres and graduated into 20 divisions. Thus, each vernier division is smaller than 2 millimetres by 0.05 millimetre (Fig. 24*d*).

In the tools accurate to 0.02 millimetre the vernier scale is 49 millimetres long and graduated into 50 divisions. In this case each division of the vernier is equal to 49 : 50 = 0.98 millimetre, i.e., shorter than the division of the beam scale by 1.00—0.98 = 0.02 millimetre.

Vernier calipers. They are intended to measure the external and internal dimensions, to scribe arcs and circles, parallel lines in marking, to divide the circles and straight lines into sections and for other jobs.

The vernier calipers have a wide measuring range of 0-125, 0-200, 0-320, 0-500 millimetres. For measuring large-size parts, the calipers are available with the beam length of 710, 1000, 1400, and 2000 millimetres.

A standard vernier caliper comprises beam *1* (Fig. 24*e*) with fixed jaws, sliding head *2* with sliding jaws, which accommodates a flat spring attracting the sliding head to the beam. The beam has the basic scale graduated in 1-mil-

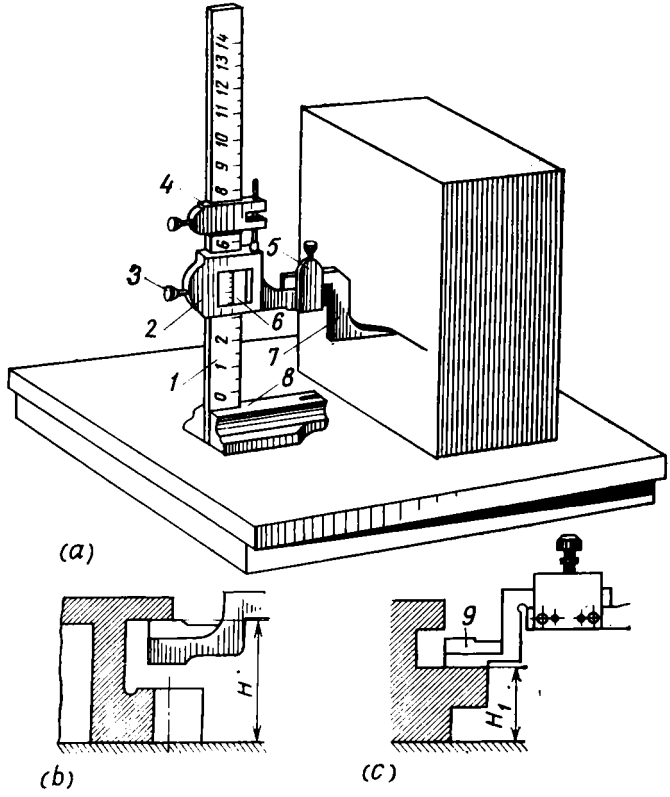


Fig. 25. Vernier height gauge

(*a*) design; (*b*) measuring the flange height (*H*); (c) measuring the shoulder height (H_1); *1*—stand bar; *2*—sliding head; *3*—clamp screw; *4*—micrometric feed; *5*—clamp; *6*—vernier; *7*, *9*—jaws; *8*—base

limetre divisions, the bevel of the sliding head has the vernier scale graduated for the required reading. Besides, there is auxiliary sliding head *4* intended for accurate adjustment to size according to the vernier by turning nut *6*. Screw *5* connected to sliding head *2* moves it over the beam.

Vernier depth gauges. This tool is used to measure height, the depth of blind holes, the thickness of walls, the depth of grooves and slots, etc. Vernier depth gauges are made with the measuring ranges of 0-200, 0-320, and 0-500

millimetres, and for readings taken with a vernier accurate to 0.05 and 0.02 millimetre. When measuring with the vernier depth gauge (Fig. 24*f*), its base *15* is brought into contact with the surface of the part from where the size is read, and beam *10* is advanced until it rests against the other surface *A* to which the distance is measured. At this position of the tool, slide *9* of micrometric feed *11* is locked by clamp *8*. Then nut *12* is turned and head *13* is arrested by clamp *7*. The reading is taken from the basic scale of beam *10* (whole millimetres) and from vernier scale *14* (fractions of a millimetre).

For measuring in difficult-of-access places use is made of a replaceable beam with a bent end (Fig. 24*g*).

Vernier height gauges (Fig. 25). These are intended for measuring the height of parts positioned on a flat surface and for the precision marking-off work done on the plate. A vernier height gauge (Fig. 25*a*) has base 8 with stand bar *1* and a scale rigidly secured in the base, sliding head *2* with vernier *6* and clamp screw *3*, micrometric feed *4* comprising a slide, a screw, a nut, and a clamp screw; interchangeable marking-off jaws *7*, height measuring jaws *9* with two measuring faces (the lower one is flat and the top one is made in the form of a pointed edge), and clamp *5* for securing jaws *7* on the boss of head *2*.

The vernier height gauges are available in the measuring range of 0-200, 30-300, 40-500, 60-800, and 60-1000 millimetres, and for reading accuracy on the vernier of 0.1, 0.05, and 0.02 millimetre.

Micrometers

These tools include micrometer calipers, inside micrometers, micrometer depth gauges, micrometer gear-tooth gauges, etc.

The micrometer employs a screw-and-nut pair in which a precision-threaded screw rotates in the fixed nut, one complete turn of the screw advances it by one pitch with respect to the nut.

All micrometric tools are threaded with a 0.5-millimetre pitch, which means that one rotation of the screw will advance its measuring face by 0.5 millimetre.

The reading device of micrometric tools comprises barrel *1* (Fig. 26*a*) and thimble *2*. On both sides of the longitudinal line of the barrel two scales are engraved with 1-millimetre divisions spaced so that the top scale is displaced by 0.5 millimetre with respect to the bottom scale. The bevelled face of the thimble has a circular scale with 50 divisions. The rotating thimble travels axially along the barrel and advances by 0.5 millimetre for one complete turn. Thus, the value of the scale division is 0.5 : 50 = 0.01 millimetre.

In taking measurements, the whole millimetres are read from the lower scale, and the half millimetres from the upper scale of barrel *1*. The hundredths of a millimetre are read from the circular scale of thimble *2* by the mark coinciding with the longitudinal line on the thimble. The examples showing how to take readings are presented in Fig. 26 (*b*, *c*, and *d*).

Micrometer calipers. Figure 26*e* illustrates a standard micrometer caliper. It comprises frame *3* with anvil *4*, micrometer screw *5*, barrel *7*, thimble *8*, ratchet *9*, and locking nut *6*. The micrometer calipers are available in the measuring range of 0-25, 25-50, 50-75, 75-100 and so on up to 500-600 millimetres. The measuring range of a tool does not influence the design of the micrometer screw head, the difference being only in the shape and size of the frame.

The micrometer screw head is fitted with a ratchet which ensures a constant measuring pressure. To take readings from the scales of the micrometer caliper, the screw is rotated by the ratchet until it rests against the work being measured and locked with a locking nut.

The micrometer calipers provide for measuring accuracy of 0.01 millimetre but experienced operators can obtain an accuracy of up to 0.005 millimetre.

Inside micrometers. These are used for measuring the diameter of holes and other inside dimensions of parts. To measure the diameters in small holes (from 5 to 55 millimetres) and the width of slots in fine recesses the inside micrometers with measuring tangs *1* (Fig. 27*a*) are employed. Such micrometers are adjusted to adjusting ring *2* which is also used in verifying the reading accuracy of the

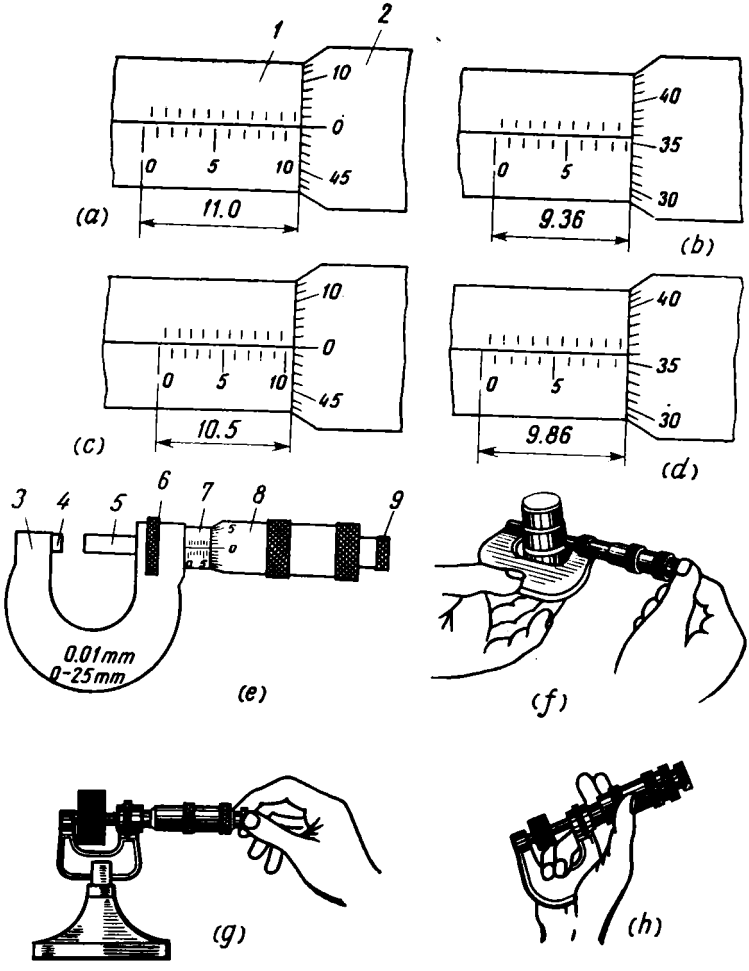


Fig. 26. Micrometric reading device

(*a*), (*b*), (*c*), (*d*) reading the sizes from the micrometric scale; (*e*) standard micrometer caliper; (*f*), (*g*), (*h*) methods how to use a micrometer; *1*, *7*—barrels; *2*, *8*—thimbles; *3*—frame; *4*—anvil; *5*—micrometer screw; *6*—locking nut; *9*—ratchet

scale. Stop screw *3* is used for locking the measuring tangs in a certain position.

Figure 27 (*b* and *c*) shows an inside micrometer caliper which comprises rod *7* having spherical measuring tip *4* at its left end. Thimble *8* is fixed with the micrometer screw which has movable measuring face *9*. If the tool is set at zero, the distance between the spherical faces is equal to 50 millimetres. The micrometer screw is threaded, the length of thread allowing an extension of this distance by 13 millimetres. Thus, the measuring range of the inside micrometer caliper is 50-63 millimetres. When the measurement has been taken, the tool is arrested by stop screw *6*.

For a wider range of measuring, the caliper can be fitted with changeable extension rods screwed in place of thread-protecting nut *5*. Extension rod *11* (Fig. 27*d*) is enclosed in cylindrical pipe *12* and receives constant pressure exerted by spring *10*. At its one end the extension rod is threaded externally, at the other end internally, which allows the extension rods of different size to be screwed up to the micrometer head, as well as to one another. The extension rods allow the measurement of parts from 50 to 1500 millimetres in size.

The caliper is set to zero by a micrometer, an adjusting ring or a precision gauge block.

Micrometer depth gauge (Fig. 27*e*) is intended for measuring the depth of slots, blind holes or shoulders up to 100 millimetres with an accuracy of up to 0.01 millimetre. The tool has base *13* carrying micrometer head *14* with measuring spindle *15*. The depth is read from the scale 25 millimetres in length. Changeable spindles (Fig. 27*f*) allow the measurements to be taken in the range of 25-50, 50-75, and 75-100 millimetres.

Precision Gauge Blocks

These are small steel blocks having two parallel, diametrically-opposite measuring surfaces (Fig. 28*a*).

The gauge blocks are made of alloy chromium steels given a thorough heat treatment and hardened to R_C 62-64; they are also machined to a high degree of precision by grinding and lapping. The nominal size between the measuring

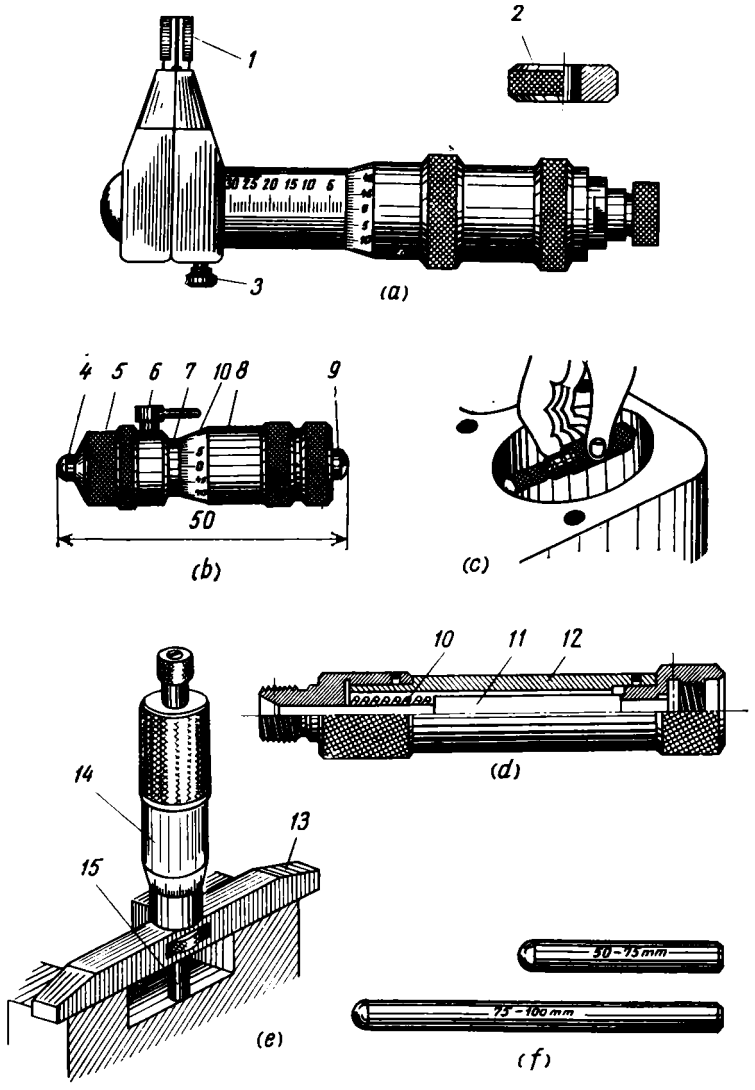


Fig. 27. Inside micrometers

(*a*) inside micrometer for measuring holes of up to 55 millimetres in diameter; (*b*) inside micrometer caliper; (c) measuring hole diameter with inside caliper; (*d*) caliper extension rod; (*e*) micrometer depth gauge; (*f*) changeable spindles for depth gauge; *1*—measuring tangs; *2*—adjusting ring; *3*, *6*—stop screws; *4*—measuring tip; *5*—nut; *7*, *11*—rods; *8*—thimble; *9*—measuring face; *10*—spring; *12*—pipe; *13*—base; *14*—micrometer head. *15*—spindle

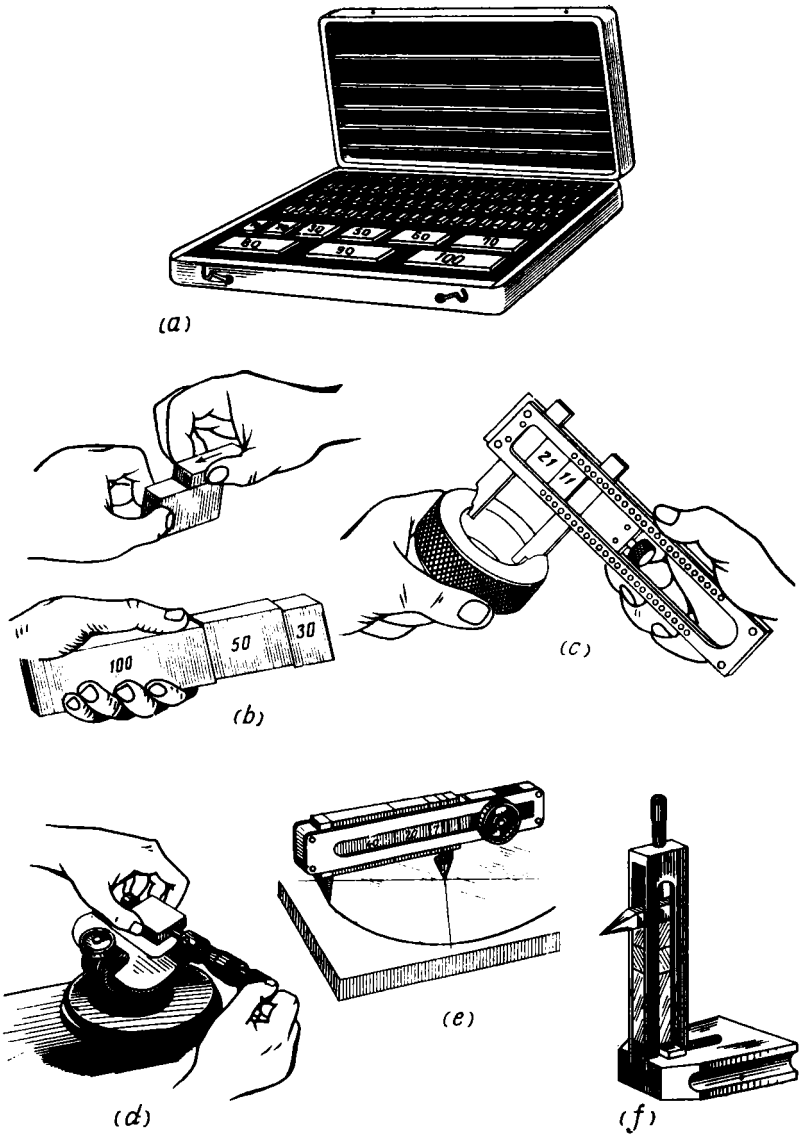


Fig. 28. Precision gauge blocks

(*a*) general view of gauge block set; (*b*) methods of "wringing" gauge blocks to one another; (*c*) measuring a hole with a gauge block; (*d*) checking a micrometer for accuracy with gauge blocks; (*e*) precision flat marking; (*f*) set of blocks for three-dimensional marking

surfaces of the gauge blocks is obtained accurate within 0.0001 millimetre and their surface finish corresponds to Class 13 or 14. This allows them to be "wrung" to one another and thus combinations of individual blocks can be used as units with pieces firmly adhering to one another (Fig. 28*b*).

Depending on the degree of precision, the gauge blocks are classified into Class 0, Class 1, Class 2, and Class 3, the first one being the most precise. The blocks are available in sets comprising 116, 87, 42, 23, 10, or 7 pieces of different size selected to combine any required set accurate to 0.005 millimetre. When making up a set of the required size first a block is taken of the one-thousandth series. The size of this block is subtracted from the size of the set required. Then a block is taken of the one-hundredth series and its size is subtracted from the remainder after the first subtraction. The sizes of the next blocks are determined in the same way. The set should consist of the minimum possible number of blocks. For instance, the block with the size of 57.845 millimetres should include at most 4 blocks:

First block	1.005
Remainder	56.84
Second block	1.34
Remainder	55.5
Third block	5.5
Fourth block (remainder)	50.0

In shop practice one will be satisfied with a set of blocks of Class 3 accuracy. Using different accessories they can be applied to check up the sizes of a precision-made part, templet or gauge, as well as to adjust measuring and marking-off tools and instruments. Figure 28 (*c*, *d*, *e*, *f*) presents some examples of different employment of gauge blocks.

Gauge blocks should be handled with due care: do not touch their measuring surfaces with your hands, never allow them to be hit, heated, scraped or scratched. When combining sets out of blocks, use the protection plates provided in the set so as to prevent rapid wear or damage of gauge blocks. After work, the set of blocks should be disassembled, washed in aviation gasoline, thoroughly wiped with

washleather or a piece of clean soft fabric, and placed in their cells of the set case. For long-term storage the blocks should be coated with commercial vaseline.

Thickness gauges. A thickness gauge is a set of thin precision-machined blades with thickness from 0.02 to 1 millimetre and up to 100 millimetres long. These gauges serve to check clearances between mating parts. In tool production, they are most extensively used in assembling the dies, adjustment of tooling equipment, and in checking whether the mould members properly contact one another.

Four sets of thickness gauges (Fig. 29) are produced in the Soviet Union: Nos 1, 2, 3, and 4 which differ in the number of blades and their thickness. The thickness of each blade is stamped on it, the set

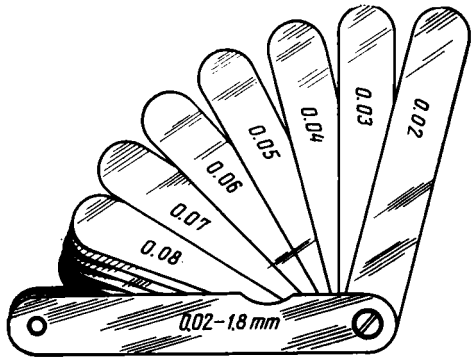


Fig. 29. Set of thickness gauges

including the blades increasing in thickness first by 0.01 millimetre and then by 0.05 millimetre. To determine a clearance, one or several appropriate blades held together can be used.

To find the size of the clearance, one or two blades are inserted and tried for a fit between the contacting surfaces until blades of suitable thickness are found.

Tools for Checking Straightness and Flatness

The parts are considered to be manufactured accurate not only when their sizes are within the prescribed limits

but also when their surfaces are straight and flat to the required degree.

The most popular tools for checking straightness and flatness are toolmakers' straight edges available in several styles (Fig. 30).

Straight edges are available with various cross sections: (a) with a double bevel, (b) three-edged, (c) four-edged. The straightness is checked by a light test (light clearance), the narrow edge of the tool being applied to the surface to be tested and a source of light placed behind the straight edge and the workpiece (see Fig. 30*h*). The absence of light between the straight edge and the surface indicates the straightness of the workpiece; straight but rather rough surface will yield uniform feeble light over the whole length of the straight edge.

With some practice, a light clearance of 0.002 to 0.005 millimetre may be detected accurately enough by the eye or using gauge blocks as shown in Fig. 30*i*. For this purpose two blocks *3* and *5* of the same size are applied to surface *1* being checked. Placed over blocks *3* and *5* is straight edge *4*. A set of measuring blocks *2* is tried into the clearance between the surface plate and the edge of the tool.

The difference between the size of blocks *3* and *5* and that of block *2* shows, thus, the deviation from straightness in the workpiece.

Straight edges with wide working surfaces fall into four types: of rectangular cross section (Fig. 30*d*), of I-beam cross section (Fig. 30*e*), of bridge type (Fig. 30*f*), and three-edged (Fig. 30*g*).

They are used for testing surfaces for straightness and flatness by linear deviations (using feeler gauges) and by the paint method. The latter consists in the following: the working surface of the straight edge is given a thin coating of marking paint (Fig. 30, *j* and *k*), the straight edge is then applied across the surface of the workpiece and the flatness of the surface is judged upon by the number of spots within an area of 25 × 25 millimetres.

A method employing strips of cigarette paper is also rather accurate. The pieces of paper are laid beneath the straight edge in several places. Then the strips are drawn from under the straight edge and the value of deviation

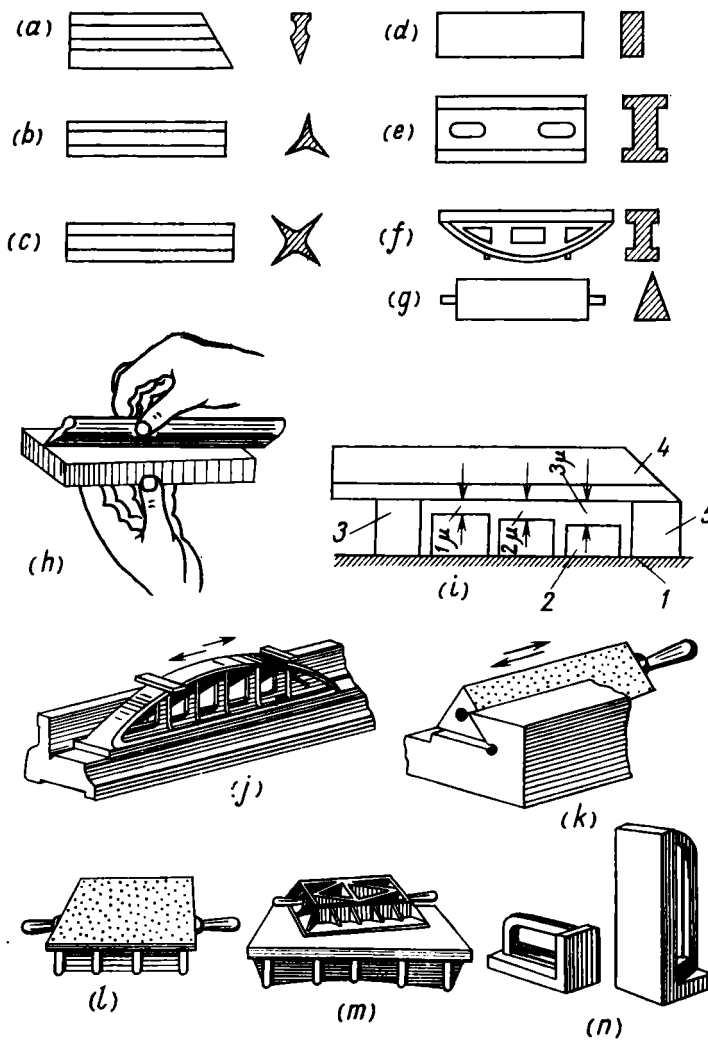


Fig. 30. Tools for checking straightness and flatness

(*a*), (*b*), (c) straight edges; (*d*), (*e*), (*f*), (*g*) straight edges with wide working surfaces; (*h*) testing for light clearance; (*i*) testing with the aid of straight edge and gauge blocks; (*j*), (*k*) testing by paint method; (*l*) surface plate; (*m*) testing the plate by paint method against another plate; (*n*) test-scraping angle plates; *1*—surface; *2*—set of measuring blocks; *3*, *5*—blocks; *4*—straight edge

from straightness is judged upon by the effort required to draw each of the strips. When the thickness of paper strips is measured by a micrometer, the clearance can be detected accurate to 0.01 millimetre. The thickness of paper is found by measuring a pack of 10 strips and dividing the micrometer reading by 10.

Surface plates (Fig. 30, *l* and *m*) are the basic means for checking the flatness by the paint method. The plates are made of high grade fine-grained cast iron; they range in size from 100 × 200 to 1000 × 1500 millimetres. The surface plates are precision-ground and then scraped. They are tested by the paint method to the master plate. The plates with the number of spots of not less than 25 over an area of 25 × 25 millimetres are ranked among the first-class plates, those with at least 20 spots are second-class plates and those with at least 12 spots are considered to be third-class.

The surface plates are used not only as testing tools but find an extensive application as a base for different checking operations in conjunction with universal measuring means.

The angle plates (scraping angles) shown in Fig. 30*n* serve for checking perpendicular surfaces by the paint method and are infrequently used as auxiliary tools in measuring, assembly, and marking.

Measuring Tools for Angles and Tapers

Angles and tapers may be measured by squares, universal bevel protractors, angle straight edges, sine bars, optical dividing heads.

Squares are used for measuring and marking of right angles, checking whether the part surfaces are mutually perpendicular during manufacture and assembly. The industry of the USSR produces squares with angles of 45, 60, 90, and 120°.

There are high-precision squares and ordinary squares for benchwork and marking. The high-precision squares are used for checking precision parts by light method. The marking-off squares have a wide beam which is firmly applied to the edge of the workpiece being marked. The

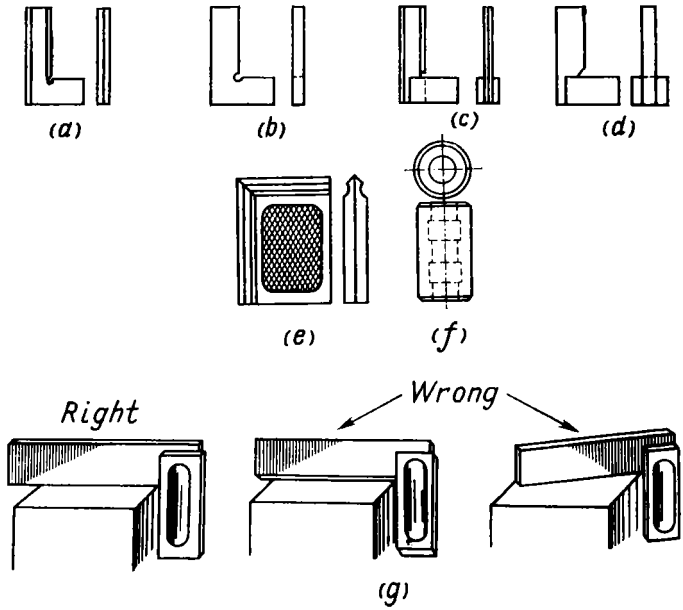


Fig. 31. Squares

(*a*) high-precision flat-type; (*b*) toolmaker's flat-type; (*c*) high-precision broad-side; (*d*) toolmaker's broad-side; (*e*) one-piece high-precision; (*f*) cylindrical; (*g*) application of square for measuring

standard establishes four accuracy classes for high-precision squares: 0, 1, 2, and 3; class 0 squares being the most precise. In all the squares one side is made longer than the other, the squares are available with the sides in the range from 32 × 50 to 1250 × 2000 millimetres. The squares with the sides exceeding 250 × 400 millimetres are made only to Class 2 and 3 accuracy and cannot be hardened.

Figure 31 (*a*, *b*, *c*, *d*) presents the squares used by toolmakers. Figure 31*e* shows a one-piece high-precision square made to Class 0 and 1 accuracy and having the size of sides of 40 × 63 and 63 × 100 millimetres. Such angles are used in conjunction with the surface plate for checking high-precision intricately-shaped parts and for testing assembled small-size high-precision dies, moulds, jigs and fixtures.

Figure 31*f* shows a cylindrical master square used in conjunction with the surface plate for testing all the other squares to see whether their 90° angle is perfectly true.

Universal bevel protractors with verniers are widely used in measuring the angles by applying them to the workpieces. Most popular are the types of protractors shown in Fig. 32 (*a*, *b*).

The protractor shown in Fig. 32*b* is most convenient in work. It employs the principle of a circular scale for measuring angles from 0 to 320°. Base *4* with measuring blade *5* at one of its ends is graduated in degrees. Sector *3* which travels over the base has bevelled arc *1* whose vernier is graduated from 0 to 60. The protractor set includes square *2* and bar *6* with bevelled measuring edge, as well as two clamps to attach the square and the bar to the protractor.

An assembled set of protractor, square, and bar allows angular measurement from 0 to 50°. With the bar and clamp removed the measuring range will be from 140 to 230°. With the measuring bar mounted instead of the square the angles from 50 to 140° can be measured. Finally, the protractor with no square or bar allows the angles from 230 to 320° to be measured. The vernier reading accuracy of this tool is 2′.

Figure 32*c* shows an optical bevel protractor. Bar *12* with a through axial slot is rigidly joined to body *16* of the protractor with glass dial *15* fixed inside it. The dial has a complete angular scale with the value of division of 1°. The scale is divided into four quadrants with numerals from 0 to 90° spaced in every 2°. Bar *8* can be moved towards its axis and turned about the centre of body *16* through a certain angle with respect to bar *12*.

In the longitudinal position bar *8* is locked by turning stop *10*.

Entering the longitudinal slot of bar *12* is a key joined to upper disc *11* which carries magnifying glass *7* of ×16 magnification and glass *14* with scales graduated into 5′ divisions.

The field of view of magnifying glass *7* covers two scales graduated into 5′ divisions and a section of circular dial *15* illuminated through glass *14*. In this case the

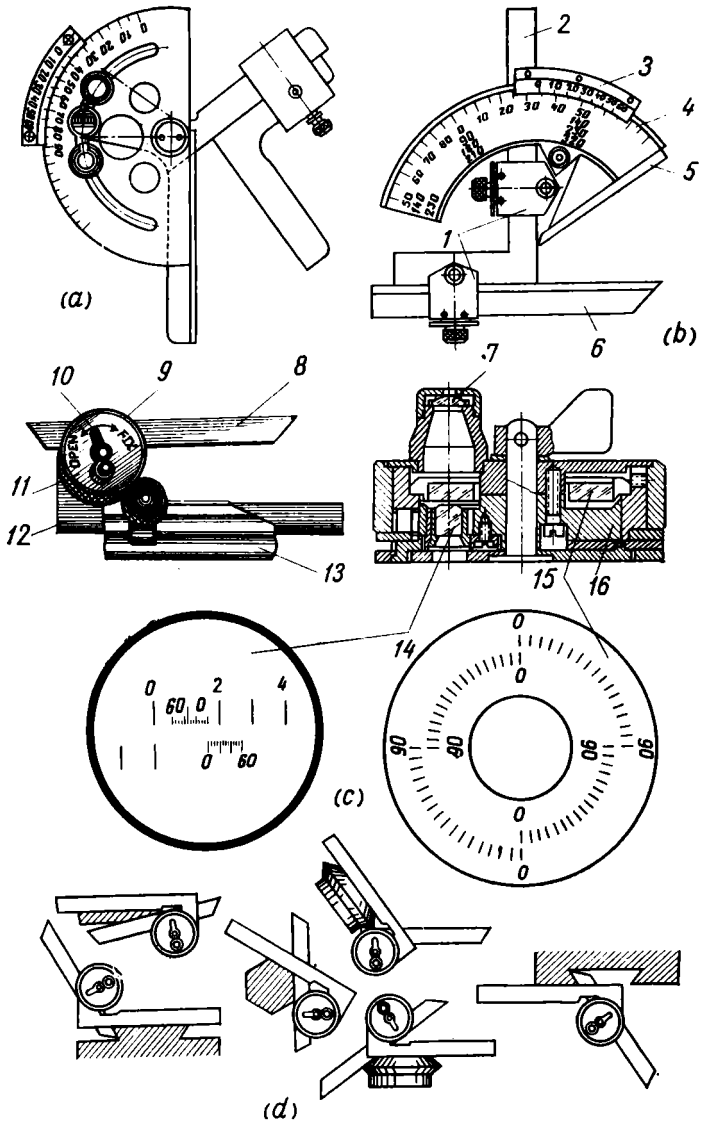


Fig. 32. Universal bevel protractors

(*a*), (*b*) design; (*c*) optical bevel protractor; (*d*) application of optical bevel protractor

reading is 1°35′, it represents the angle between bars *8* and *12*.

The angle between these bars is set by turning knurled rings *9* clockwise and locked by stop *10*. Support *13* with flat surface and prismatic recess serves for mounting the protractor on the flat or cylindrical surface in marking-off and assembly-testing jobs.

Plane angle gauges (Fig. 33). The angle gauges, made in the form of flat prisms, are intended for conveying the

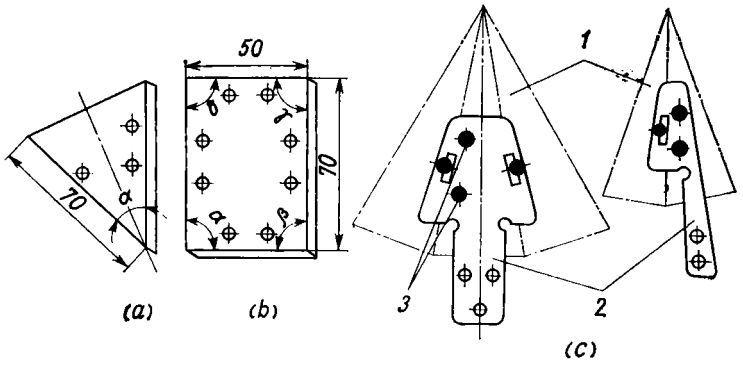


Fig. 33. Plane angle gauges

(*a*) acute-angle plate with one working angle (α); (*b*) angle plate with four working angles; (*c*) plate blocks; *1*—plates; *2*—holders; *3*—fastening screws

unit of a plane angle, for testing and calibrating angle-measuring tools, templets and instruments, as well as for marking and testing of angular parts.

Plane angle gauges are available in the following types: *I*—angle plates with one working angle having a truncated apex; *II*—acute-angle plates with one working angle (Fig. 33*a*); *III*—angle plates with four working angles (Fig. 33*b*); *IV*—hexahedral prisms with a nonuniform angle pitch; *V*—polyhedral prisms with a nonuniform angle pitch.

The type *I* plates are graduated in 2′ and 1°; the type *II* plates in 15″, 1′, 10′, and 1°; the type *III* plates in 10′ and 1°; the type *IV* and type *V* plates in 30° and 45°,

The plane angle gauges are available in three classes of accuracy (0, 1, and 2) with the tolerances of $\pm 3''$, $\pm 5''$, and $\pm 10''$, respectively.

The measuring surfaces of the plane angle gauges are capable of being wrung to one another. These tools are available in sets with a straight edge for each set and with a series of holders having holes and clamps for holding together several plates assembled in a block (Fig. 33*c*), the plates also having several holes.

Sine bars (Fig. 34*a*) are precision instruments used for marking, setting, testing, and otherwise dealing with angular work. The sine bar is a rectangular precision-ground hardened steel bar *3* with two prism-shaped shoulders cut out in the side edges. Secured in the shoulders are precision ground cylindrical rolls *1* and *5* of a certain diameter *d*.

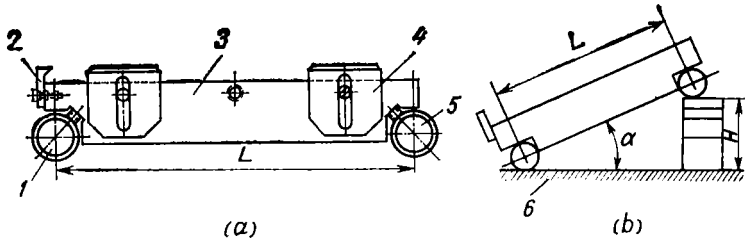


Fig. 34. Sine bar

(*a*) design; (*b*) calculations used in plotting or testing the angles; *1*, *5*—rolls; *2*, *4*—rests; *3*—bar; *6*—surface plate

The rolls are arranged at a prescribed distance L. Rests *2* and *4* may be screwed to the side edges. The top of the bar is provided with plain and threaded holes to hold the work.

The sine bar is adjusted for the required angle α with respect to surface plate *6* by inserting a stack of gauge blocks under roll *5*, the height of this stack H being found from the formula

$$H = L \sin \alpha \text{ mm}$$

With the height H of the gauge blocks known the obtained angle is calculated from the formula

$$\sin \alpha = H/L$$

The basic dimensions of standard sine bars are as follows:

Centre-to-centre distance between the rolls	100, 100, 200, 200
Width of the working plane	25, 100, 50, 150
Roll diameter	20, 20, 30, 30

The errors in plotting angles with a sine bar may be $\pm 1.5'$ for angles up to 4°; $\pm 2'$ for angles up to 10°; $\pm 2.5'$ for angles up to 20°; $\pm 3.5'$ for angles up to 30°; $\pm 6'$ for angles up to 45°.

Optical dividing heads (Fig. 35*a*). These are intended for angular measurements, indexing operations, and angular marking when machining intricate parts.

The head has a tailstock with a spindle and a centre. The tailstock is mounted on bed *7* with a longitudinal groove receiving the guide slides of head body *6*. At its nose spindle *8* is provided with a Morse taper locating hole *5* which receives the centre tang, the work with a tapered tang or the tang of a clamping self-centering chuck.

By turning handwheel *1* connected with worm *15* of the worm drive, spindle *8* is revolved together with worm gear wheel *13* attached to it and main dial *12* with a circular scale graduated in 1° divisions.

Reading device *4* serves for reading the angles through which spindle *8* is revolved, the spindle then being locked by crank *2* of the clamping mechanism.

The dividing heads are available in several types depending upon the required reading value from 2 to 60 seconds.

Figure 35*b* shows a design of an optical head with the reading value of 2″. The light flux goes from source *11*, passes through the condenser, and reflects from the mirror to illuminate a section of the circular scale of dial *14* with 1° divisions, which is examined by the reading microscope comprising an object-glass, an eyepiece, and scale *9* arranged between them. Placed between the object glass and the eyepiece are two internal total reflection prisms intended for changing the direction of the light beam flux and for better reading observation.

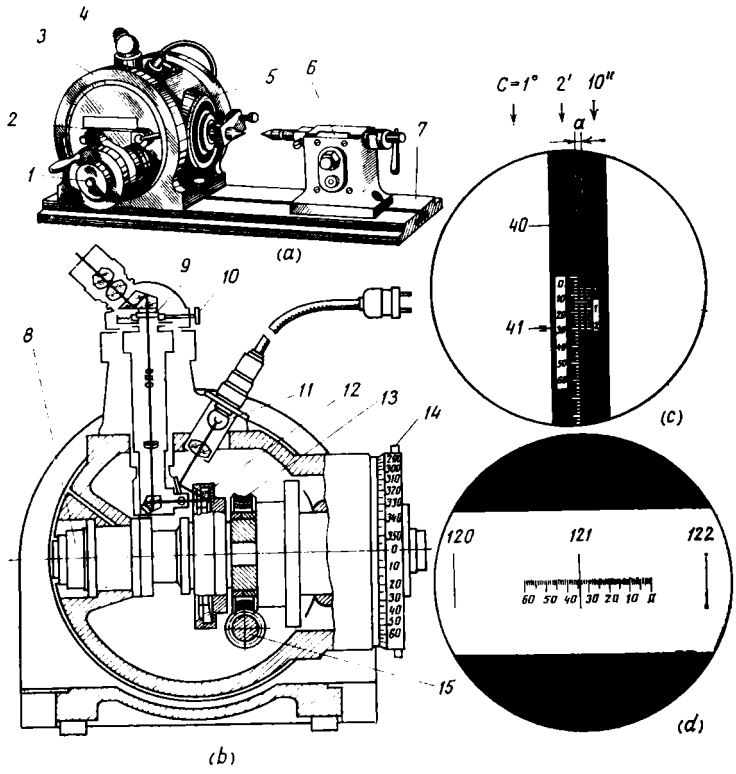


Fig. 35. Optical dividing head

(a) general view of head and tailstock mounted on bed; (b) design; (c) head field of view with reading value of 2″; (d) head field of view with reading value of 60″; *1*—handwheel; *2*—crank; *3*, *6*—bodies; *4*—reading device; *5*—locating hole; *7*—bed; *8*—spindle; *9*—scale; *10*—micrometric screw; *11*—light source; *12*—main dial; *13*—worm gear wheel; *14*—dial; *15*—worm

Scale *9* can be shifted by micrometric screw *10*. Spindle *8* with the main dial attached to it, worm gear wheel *13*, dial *14* for approximate setting, and the centre is set in motion by worm *15* linked to the crank.

Figure 35*c* shows the field of view displaying the moving scale at the section of 1° with the value of divisions of 2′, the vernier at the section of 2′ and with the reading value

of 10″, as well as a section of the circular scale with 1° divisions.

The scales with 2′ and 10″ divisions are made transparent against the black background. They are arranged against one another and separated by a narrow strip with the width of *a*. When the scale with 2′ divisions moves, the bisector in the form of a double short line moves too. The degree lines can be seen in the view field reflected from the degree dial. The scale with 2′ divisions is moved so that the line of the degree scale is introduced into the clearance of the bisector, then the reading is done.

The reading, as shown in Fig. 35, of 41°5′40″ is taker as follows: 41°—to the line in the clearance of the bisecton connected with the scale of 2′ divisions; 5′—to the indicator at the zero line of the vernier; 40″—to the number of lines of the vernier between the zero line and the illuminated line on the band of width *a*.

In optical dividing heads with 60″ divisions, there is no micrometric screw and fixed scale *12* is graduated in 1′ divisions. Figure 35*d* shows the view field of the optical dividing head with such a scale. The reading is 121°34′.

Electromagnetic swivel marking-off devices. Figure 36 shows a marking-off device which is essentially an electromagnetic clamping plate able to swivel round two mutually perpendicular axes. This allows the work, pressed against the plate electromagnetically, to be mounted in any position with respect to the marking-off plate according to the high-precision scales in both directions of swivelling.

The device can be used both for marking and checking up the workpieces or finished products. The size of the clamping plate is 245 × 450 millimetres.

The plate can swivel through 360° horizontally and through 180° vertically, the direct indexing being through 45° by locking pins in the flange. The mass of the work can be within 30 kilograms. The mass of the electromagnetic device is about 90 kilograms.

Lever-type measuring tools. The most wide-spread lever-type measuring tools are indicators, lever micrometers, lever snap gauges, microkators (spring type comparators with scale division values as small as 1 μ).

In the manufacture of tooling equipment most popular

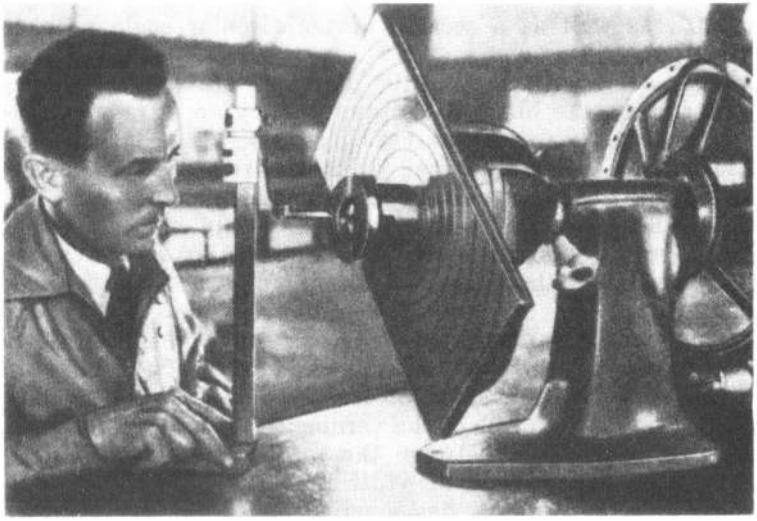


Fig. 36. Electromagnetic swivel marking-off device

are dial indicators with a scale division value of 0.01 millimetre.

These tools are intended for measurement of relative or comparative deviations in the size of parts and for determining errors in geometrical form, as well as for testing the position of mating surfaces. They are used to verify whether the workpiece planes are horizontal or vertical, whether there is any ovality or taper in solids of revolution or holes, misalignment in the shaft and hole pairs, run-out of pulleys, spindles, gear wheels, and other revolving parts.

The indicators employ the principle of a special rack gearing train which converts slight linear displacements of the measuring spindle into amplified and easily readable movements of the pointer along the circular scale.

Two types of dial indicators are available: I—those with the measuring spindle moving parallel to the scale, and II—those with the measuring spindle moving perpendicular to the scale (end type).

Type I indicators have the measuring ranges of 0-5 and 0-10 millimetres, type II indicators measure in the range of 0-2 and 0-3 millimetres. The industry produces indicators with pointers turning several times round the dial graduated in 0.001 millimetre and the measuring limit up to 2 millimetres.

The indicators shown in Fig. 37 (*a*, *b*) comprise case *1*, stop *2*, dial *3*, rim *4*, counting pointer *5*, revolution counter *6*, lug *7*, sleeve *8*, measuring spindle *9*, and tip *10*. The tool scale is set at zero by turning scale rim *4*. The indicators are secured in the posts (Fig. 37*c*) by means of lug *7* or sleeve *8*.

Figure 38 shows several applications of the dial indicators.

5.5. Three-Dimensional Marking and Tools Involved

In the manufacture of tooling equipment one cannot obviate marking which calls for a marking-off plate and special-purpose tools. The preceding sections have dealt with the tools equally applicable for measuring and marking. These are vernier calipers, height gauges, gauge blocks with marking-off accessories, universal bevel protractors, dividing heads, sine bars, etc. However, three-dimensional marking calls for special tools, accessories, and devices to spare labour and time consumed in this type of operations.

Mounting Devices

Prior to marking, the work is mounted and verified on the marking-off plate using rest supports, V-blocks, boxes, mounting squares, jacks, special swivel devices.

Marking-off plates are most often available in the following range of sizes: 300 × 400, 400 × 400, 450 × 600, 500 × 800, 750 × 1000 millimetres.

The maximum permissible out-of-flatness of such plates is from ±0.035 to 0.05 millimetre depending upon the size of the plate. The flatness of the plate is verified by a straight edge for light clearance, by means of a feeler gauge or a stack of gauge blocks. The plates for extra-precision work are verified by the paint method, the required flat-

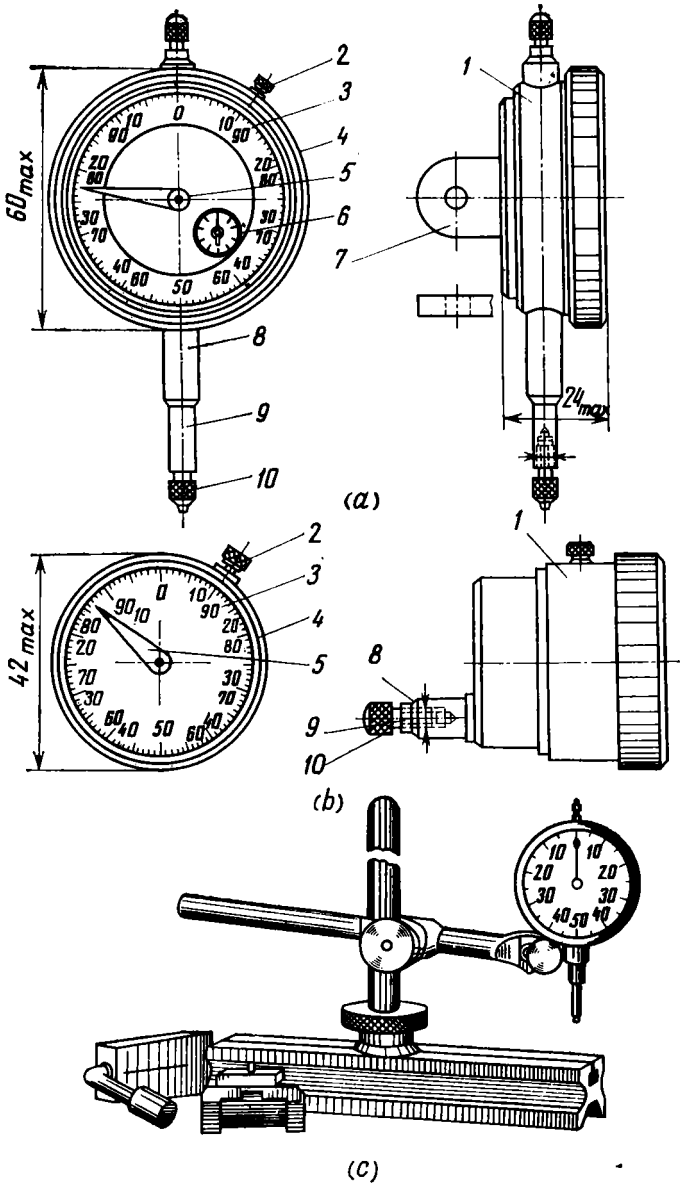


Fig. 37. Dial indicators

(*a*) with measuring spindle moving parallel to scale; (*b*) face-type; (*c*) indicator complete with post; *1*—case; *2*—stop; *3*—dial; *4*—rim; *5*—counting pointer; *6*—revolution counter; *7*—lug; *8*—sleeve; *9*—measuring spindle; *10*—tip

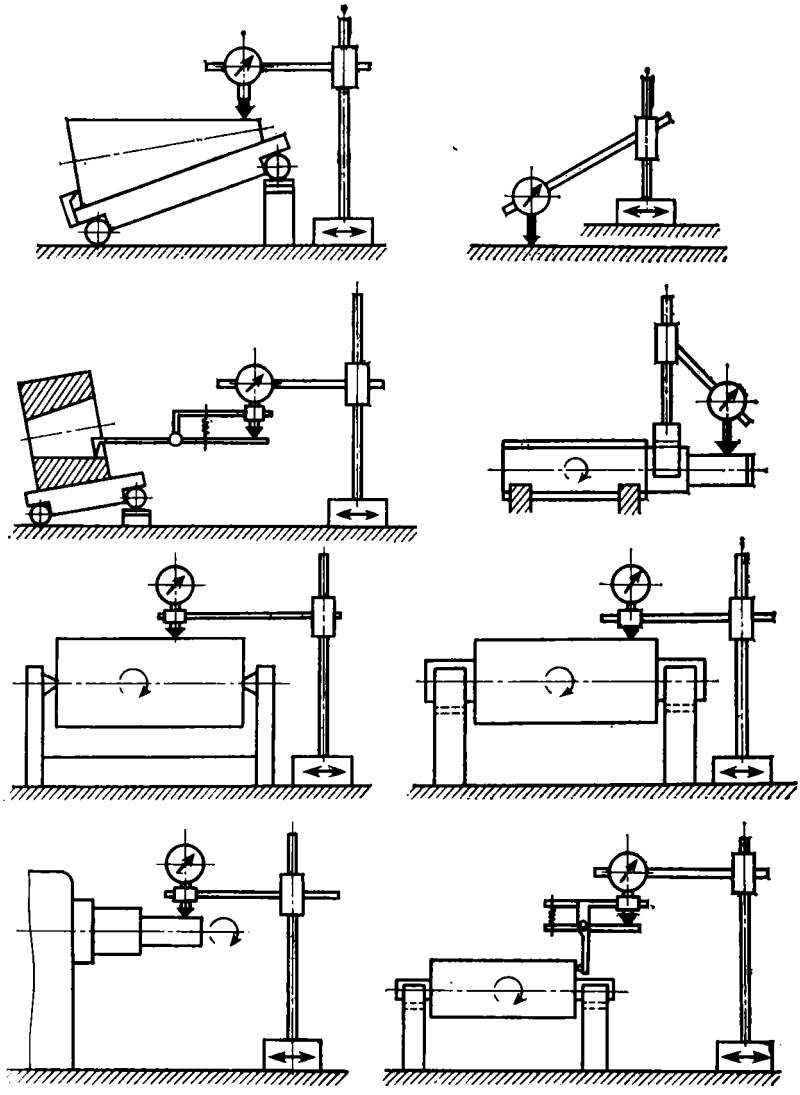


Fig. 38. Applications of dial indicators

ness being not worse than 12 spots over a 25 × 25 millimetres area.

Supports and V-blocks. The supports can be flat, box-shaped (Fig. 39*a*), or I-beam shaped (Fig. 39*b*); they can also take the form of V-blocks (Fig. 39*c*). The most convenient are universal V-blocks with a clip (Fig. 39*d*) which allow not only accurate mounting and securing of the work but also its turning through 90° and 180° without violating its accurate position.

The universal V-blocks with clips can be of different shapes to suit different applications. They are made of tool chromium steels and hardened, their surfaces being precision-ground. Any set of marking-off accessories contains several V-blocks, some of them constitute mating pairs, others are of different sizes.

There are also magnetic V-blocks (Fig. 39*e*) with permanent magnets or electromagnets.

Figure 39*f* shows an adjustable V-block consisting of two steel wedges which are hardened and precision-machined. The work to be marked is mounted on the surface of the top wedge and lifted or lowered by turning the screw which moves the top wedge with respect to the bottom one. Figure 39*g* shows a support with a lift screw.

When mounting the castings to be marked, use is made of screw jacks (Fig. 39*h*), cast-iron marking-off squares (Fig. 39*i*), and marking-off boxes (Fig. 39*j*) with a number of slots to fix the workpieces for convenient marking by means of clamps, bolts, or screw clamps.

Special marking-off tools and their applications. Marking will be efficient if the workman is skilled in using his tools and knows well their particular applications.

Figure 40*a* shows a *universal scale rule* with a moving angle centre finder. Both edges of such rules are graduated. Besides, on one plane the graduation is metric, on the other it is in inches.

Spring dividers with a split nut are convenient to quickly set the legs for the required size (Fig. 40*b*).

Figure 40*c* shows *universal vernier calipers with changeable legs* for different marking-off operations on intricately shaped workpieces. By moving the flat scribing leg vertically and changing the centre legs it is possible to scribe

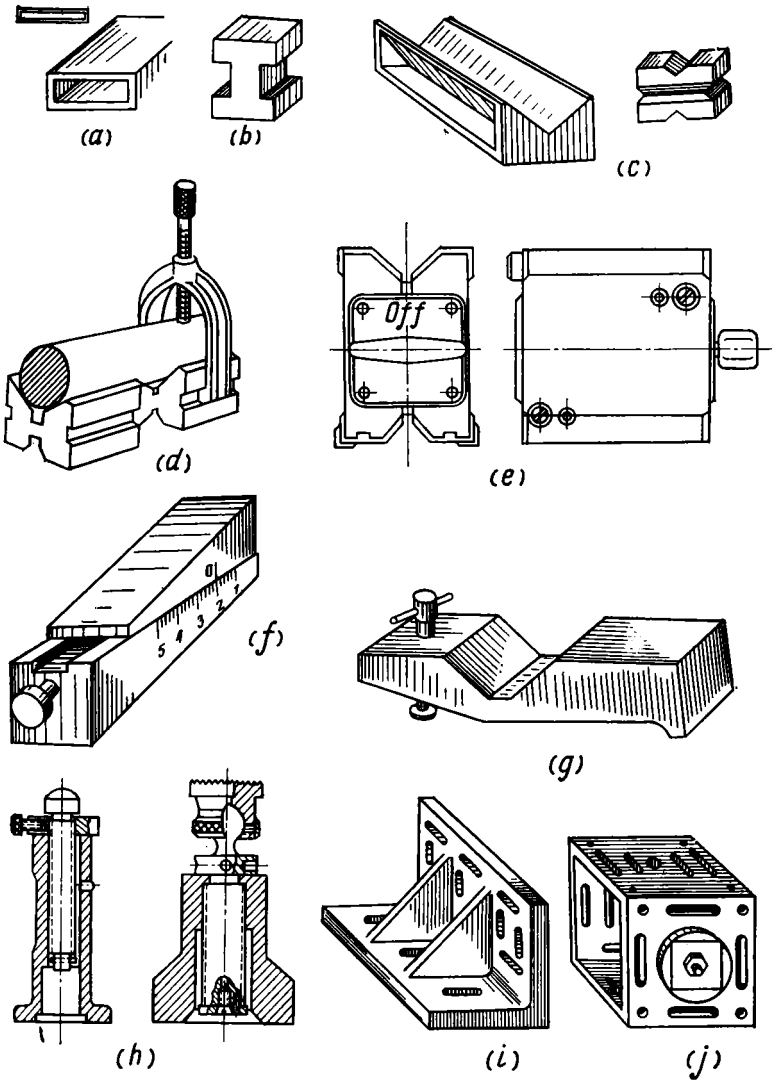


Fig. 39. Supports for three-dimensional marking

(*a*) box-shaped; (*b*) I-beam shaped; (*c*) V-blocks; (*d*) set of V-blocks with clips; (*e*) electromagnetic V-blocks; (*f*) adjustable V-block consisting of two wedges; (*g*) support with lift screw; (*h*) screw jacks; (*i*) cast-iron marking-off square; (*j*) marking-off box

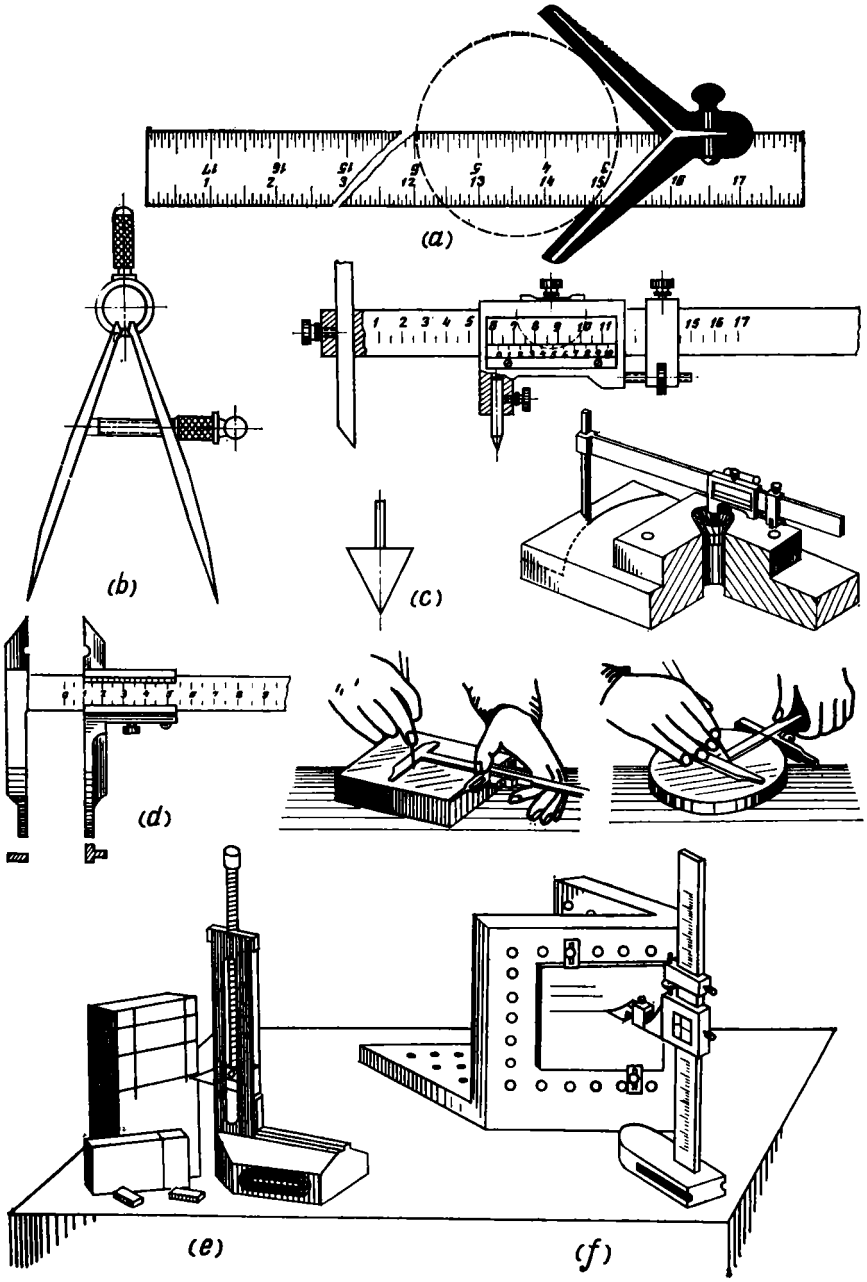


Fig. 40. Marking-off tools of advanced design

(*a*) universal scale rule with centre finder; (*b*) quick-setting spring dividers; (*c*) universal marking-off vernier calipers; (*d*) calipers for flat marking; (*e*) using gauge blocks for marking on plate; (*f*) using height gauge for flat marking

circular lines on the surfaces in different planes or marking the dimensions from the centre of the drilled or bored hole.

Marking can also be performed by means of several other calipers with a design modified to be suitable for specific marking-off jobs. The *calipers with flat legs* shown in Fig. 40*d* serve for rapid marking on the surfaces counting the dimensions from the edge of the work.

For high-precision marking use is made of *marking-off holder* and *gauge blocks* in conjunction with a special flat scriber (Fig. 40*e*).

Flat marking can be done quickly and accurately on the marking-off plate using a cast square for three-dimensional marking to which the workpiece should be attached (Fig. 40*f*). The work is done with the aid of a height gauge or a marking-off holder with gauge blocks.

Figure 41*a* shows a modified surface gauge for marking.

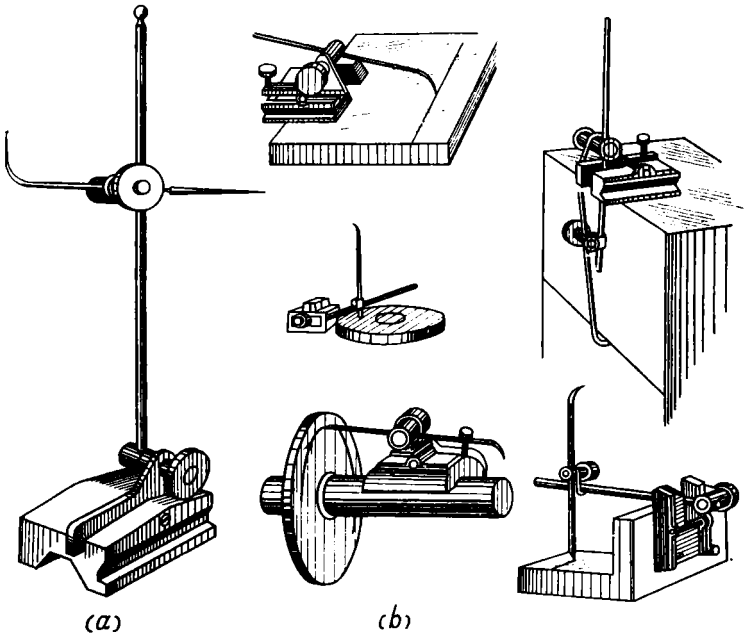


Fig. 41. Universal surface gauge (*a*) and its application (*b*)

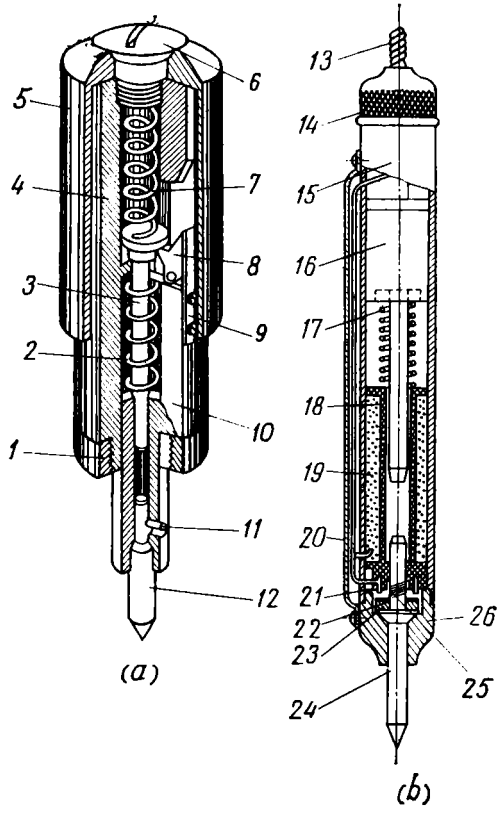


Fig. 42. Prick-punches of advanced design

(*a*) power prick-punch; (*b*) electromagnetic prick-punch; *1*—nut; *2*—return spring; *3*—striker; *4*, *26*—bodies; *5*—casing; *6*—plug; *7*—striking spring; *8*—pawls; *9*—flat springs; *10*—slide; *11*—pin; *12*—punch; *13*—feed wire; *14*, *15*, *20*—lids; *16*, *24*—strikers; *17*, *25*—springs; *18*—solenoid coil; *19*—winding; *21*—terminal pins; *22*—brass ring; *23*—ebonite washer

The surface gauge scriber is first set for an approximate size and fixed by a clamp which is locked on the upright by a fly nut, then the scriber is finally adjusted on the base by turning the adjusting screw which tilts the upright. Such tools are available in different sizes with the height of the upright from 200 to 500 millimetres and

its diameter from 7 to 16 millimetres. The size of the base varies respectively.

The recent years have seen much improvement in prick-punching tools. There are now several types of spring-, pneumatic-, and electrically-actuated punches. Figure 42*a* shows a power punch which is more convenient and reliable than similar tools of conventional design. It allows control of the punching effort which is very important for high-precision marking.

This prick-punch is self-cocking. Body *4* has two central holes bored on two sides; between the holes there is a web. The rod of striker *3* passes through the hole of the web. Resting against the collar of the striker is striking spring *7* whose other end is forced by plug *6* which holds casing *5* in place. The other hole of the body receives return spring *2* whose one end rests against the web and the other against the shoulder of slide *10*.

The slide moves freely in the lower central hole and its bosses slide over the longitudinal slots of the body. The axes of bosses have pawls *8* forced by flat springs *9* against the collar of the striker. Pin *11* secures punch *12* in the hole of the slide. The slide is secured with nut *1*.

When pressing against casing *5* with the hand downwards, body *4* goes down over slide *10* compressing the striking and return springs till the bevel of pawls *8* reaches the bevel of the longitudinal slots. The pawls slide over the bevels and turn about their axes to slightly force away flat springs *9* and release the collar of the striker. Actuated by the striking spring, the striker will strive downwards and strike against punch face *12* whose sharp point will produce a blind hole on the surface being marked.

When the pressure is removed from the punch, its striking spring will be released and the return spring will move the slide downwards till the pawl tooth engages with the striker collar. This will return all the punch parts into their initial positions making the tool ready for the next strike.

The striking and return springs are of the same external diameter and have the same number of coils with the equal pitch but the diameters of their cross sections differ, being 0.8 and 1.2 millimetres, respectively. This allows

the springs to be interchanged to vary the striking force and, consequently, the blind holes made by the punch. For obtaining very deep holes the tool is pressed against by the hand several times without displacing it.

Electromagnetic punch (Fig. 42*b*) requires no effort on the part of the operator. Body *26* of the tool is provided with solenoid coil *18* having winding *19* of enamel wire 0.2 millimetre in diameter (6000 turns). The coil is connected to feed wire *13*, protected by lids *14*, *15*, and *20*, when its terminal pins *21* are closed by brass ring *22* forced into ebonite washer *23* with the body pressing against striker *24*. When this is done the current passes through the coil and attracts the core of striker *16* which strikes against the striker rod. Spring *17* returns the striker into its initial position and spring *25* opens the coil when the punch is taken off the surface being marked.

5.6. Special Features Involved in Marking of Forging Dies

Marking is of much importance when manufacturing drop hammer dies.

Prior to marking the die blanks machined on all six sides and having no locks, the face and support surfaces are ground on a surface grinding machine to obtain accurate datum surfaces and to remove lines left after previous machining. In the dies with locks, when grinding is impossible, only large lines on the curved surfaces are trimmed away from the face of the die using hand power grinders.

The die can be marked by one of the two methods:

(1) from the centre (taken as the datum is the axial line corresponding to the axis of the shank and transferred vertically on the die parting plane);

(2) from the reference corner (taken as the datum is the side of the reference corner, which is planed or milled parallel to the axis of the shank).

The latter method is time-saving and accurate. When slight displacement of the impression occurs (within 1-2 millimetres) with respect to the shank axis, it will not cause any error, since it will be equal in the top and bottom half members of the die. This is why the two half members

of the die are marked simultaneously by transferring the dimensions from one half member to the other.

In marking the two half members of the die are mounted on the marking-off plate so that the front reference sides face the operator and the lateral sides face outwards (to the right and to the left from each other as if an unfolded book). The sides of the reference corner act as coordinate axes from which the impressions are marked in both half members of the die, therefore when the members are mated so that the reference corners coincide, the impressions are to coincide too.

The drawing should be consulted for the assumed shrinkage of the stamped part when it cools off; all the dimensions are calculated using the contraction metre.

To mark the surface and lock, different methods are used. When marking on the surface, the three-dimensional contour of the part to be stamped should be imaginarily divided into separate geometrical bodies from which the figure of the part is made up, marking is then done for each element of the geometrical bodies. Two versions are possible: the body is cut out as an element of the impression in the die solid and, on the contrary, the mass surrounding the body is removed from the die metal and the body itself is left as a projection.

When marking the die for making parts having the shape of a parallelepiped with the base *abcd*, and height *h*, a rectangle $a_1b_1c_1d_1$ (Fig. 43*a*) is arranged on its face, the sides of the rectangle exceeding the corresponding side of the parallelepiped base by the size of the die draft. Thus, the side a_1d_1 is found from the equation:

$$a_1d_1 = ad + 2h \tan 7°$$

and the side a_1d_1 from the equation:

$$a_1b_1 = ab\ 2h \tan 7°$$

Thus, the die cavity is marked not according to the shape of the parallelepiped but to the truncated pyramid: the larger base of the pyramid is made up by marking, while the sizes of the smaller correspond to the drawing of the part. Thus, both for the parallelepiped and the right prism

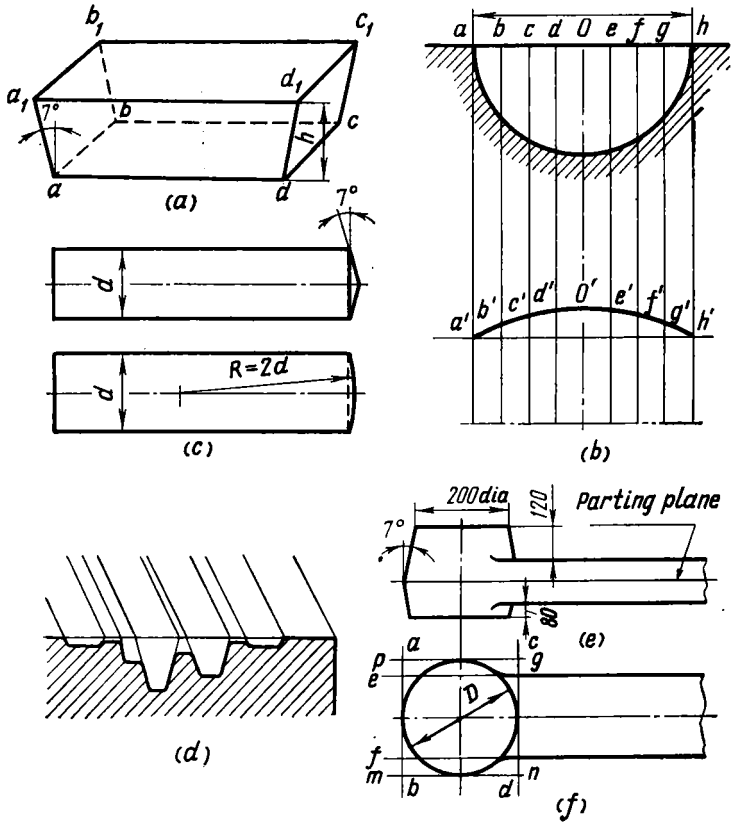


Fig. 43. Marking of die impressions

with a triangular or multiangular base marking on the face of the die is the same geometrical figure as in the prism base, but enlarged by the value of the die draft.

If the die surface is marked not for a concave but for projections, the die draft is not added but subtracted from the sizes of the part base. This method may be applied to mark both prisms and cylinders with a base as a flat figure comprised of straight or of straight and curved lines. For instance, marking of the horizontal cylinder on the die is a rectangle with the sides equal to the diameter and the

height of the cylinder. However, the flat ends of the cylinder are to have a die draft, and marking of the ends of the horizontal cylinder on the die is changed accordingly (Fig. 43*b*).

The depth of the impression varies within the points of the straight *ah*, hence the deviation equal to the die draft is not constant. If the deviation at point *a* is zero, then at point 0 it is $\frac{D}{2}$ tan 7°, i.e., it is maximum, while at the intermediate points *b*, *c*, *d*, etc., it has some intermediate values. Therefore, the line connecting the points of deviation for a die draft *a'*, *b'*, *c'*, *d'*, 0', etc., is not a straight but a curved line (an arc of an ellipse) which is to be marked on the face of the cylinder. In shops such curves are not plotted but the cylinder face is marked in a more simple way, by drawing straight lines on the face at an angle of 7° or circumscribing an arc with a radius equal to two diameters (Fig. 43*c*).

Thus, marking is reduced to drawing, on the face of the die, the figure which is produced when the part to be stamped is cut by the die parting plane. In addition to the contour of the impression with a draft die allowance, the parting plane is also given the lines of all the vertical and inclined surfaces intersecting the parting plane, even when such surfaces do not reach the parting plane (Fig. 43*d*).

Let us consider marking of a flat lever with a round head. Figure 43*e* is the drawing of a part, and Figure 43*f* shows the technique of marking the part. The parting plane divides the head into two asymmetrical parts. With the diameter of the head $D = 200$ millimetres, the marking-off diameter is

$$D = 200 + 2 \times 120 \tan 7° = 229.5 \text{ mm}$$

The diameter *D* of 229.5 millimetres is to be observed for the two half members of the die. This is why, in the bottom half of the die, when the head is milled to this marking to the depth of 80 millimetres, the diameter will be 229.5—2 × 80 tan 7° = 209.9 millimetres and not 200 millimetres as it should be according to the drawing. Therefore, when the base diameters are to be kept equal (i.e., equal to 200 millimetres) in the two half members, the die draft in the

shallow impression is changed from 7° to another which is found from the formula:

$$\tan\alpha = \frac{229.5-200}{2} : 80 = 0.185$$

hence $\alpha = 10.5°$.

For milling such a draft a shank cutter is specially sharpened.

When marking such an impression, the circumference of the base with the diameter D is enclosed in a square (see the figure) marked to obtain correct milling on four sides *ab*, *cd*, *pg*, *mn*. The same purpose is served by the marking-off lines *e* and *f* extended beyond the impression.

Marking on the lock, i.e., drawing lines parallel to the reference corner (Fig. 44*a*), does not differ from usual mark-

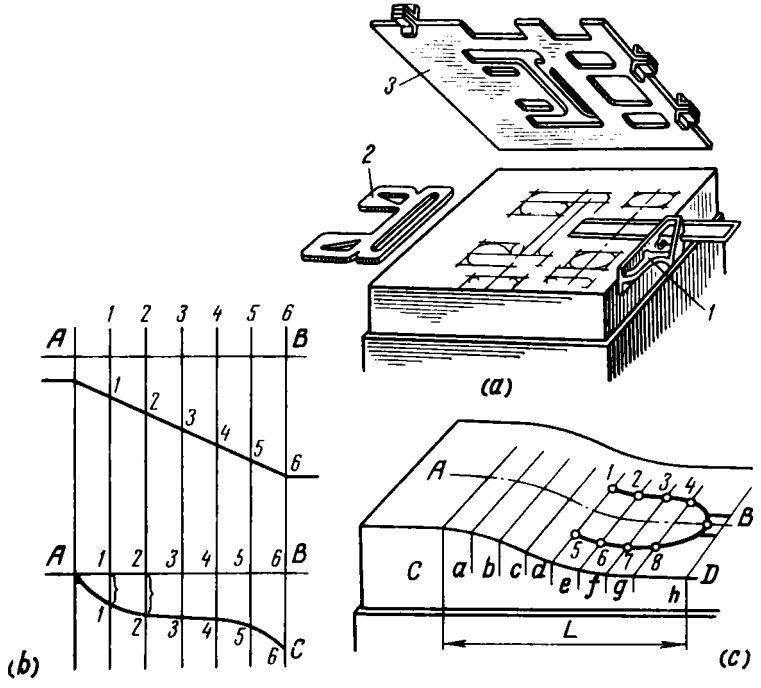


Fig. 44. Marking on the die lock

ing, since the lines can be drawn both on the inclined plane and the curved surface with the aid of a square with an extension rule or a combination protractor with an extension rule.

The curved line on the inclined plane is marked in the following way (Fig. 44*b*). First the curve line *AC* is drawn on the plane and then the coordinates of points *1*, *2*, *3*, etc., are determined, the points being spaced at the equal distance on the straight line *AB*. The length of the inclined plane is divided into the same number of parts and the axis *AB* is drawn thereon, then the separate points of the curved line are plotted and connected by a templet or an elastic rule. The more the number of divisions, the more accurate the marking.

The curved lock is marked in a similar way. With a slight curvature the inaccuracy due to distorted marking can be neglected. With larger curvature plotting is done according to the points. In this case (Fig. 44*c*), the curved lock is provided with an axial line *AB* and terminal lines confining the curved line, then these lines are transferred onto the surface of the reference corner. The distance *L* between the extreme lines *CD* is divided into sections so that the divisions coincide with the most characteristic points of the curve being marked. Those divisions are drawn on some other plane (some kind of plate) where the part outline is marked.

Thereafter the distance between each point and the axial line is measured, and the obtained values are plotted accordingly onto the face of the die and the points are connected by an elastic rule and prick-punched.

Using templets allows marking of dies to be made considerably easier while saving time, this is especially so with large dies. If the face has no lock, marking is reduced to the correct positioning of the templet, drawing its contour around with a scriber and prick-punching. The templet is mounted by means of three squares (see Fig. 44*a*), the direction of the axial line of the die being verified either to the edge of the templet when it is parallel to it, or to the axial line of the templet and the reference corner. After the contour of the templet is drawn around, marking is supplemented with axial, auxiliary, and other lines, and prick-punched.

Section II

PRESSWORKING TOOLS

Chapter 6

Fundamentals of Pressworking

6.1. Pressworking Operations

Pressworking is one of the most advanced and extensively used methods of metal working. As compared to other methods, it is more efficient and less labour-consuming while offering a sparing use of materials and yielding adequately accurate products. In most cases, pressworking is the final operation requiring no further machining.

Pressworking equipment includes different presses and tools known as *dies* or *press tools.*

All the pressworking operations can be classified into cutting and forming.

Cutting operations include shearing, blanking, cutting-out, piercing, notching, slitting, trimming, severing, and shaving.

Forming operations include bending, curling, drawing, stretch-wrapping, forming, flanging, beading, stretching, squeezing, straightening, as well as swageing, three-dimensional shaping, upsetting, cold extrusion, sizing, caulking, branding, and marking.

Pressworking practice also makes use of *combined stamping operations* which are in fact two or more different operations performed within one process, for instance shearing and bending, blanking and drawing, blanking and coining, etc. The combined operations can be performed either in progressive dies wherein all the operations and operational elements are performed in succession in several strokes of

the press (which means that each stroke of the press yields a ready article), or in combination dies wherein all the operations are performed in one stroke of the press.

Combining several operations in one die saves labour, cuts the time of the manufacturing cycle, reduces the number of dies and pieces of equipment and the number of transfer operations. Besides, combined operations contribute to greater accuracy of manufactured parts and make way for mechanization and automation of pressworking. Difficulties involved in making combination dies and their high price pay back in the form of reduced expenditures on production of one article.

As to the kind of blanks used, pressworking operations can be classified into sheet-metal working and cold die forging. Sheet-metal working employs sheets, strips, bands, and sometimes pieces of wire, whereas cold die forging utilizes plates, bars, and rolled sections.

Sheet-working operations can be performed on different materials, including steel, copper, brass, bronze, aluminium and aluminium alloys, magnesium alloys, titanium and titanium alloys. Non-metallic materials that can also be subjected to sheet working include plain and resin-impregnated paper, cardboard, cloth, fibre, celluloid, asbestos sheets, rubber, leather, and others.

Whether or not a material lends itself well for pressworking can be found by testing it for stretching, shearing, bending, deep drawing, etc. All tests are done on special machines and instruments.

6.2. Cutting Operations

Shearing sheet metal. In pressworking shops blanks for different workpieces are made from flat stock (strips and bands).

The sheet is first cut into strips or separate blanks of required size. Shearing, i.e., cutting the stock along an open contour, is done by shears with parallel blades (one blade is fixed and the other movable), or guillotine shears with the top (movable) blade inclined to the bottom (fixed) one. Blanks can also be cut from the strips and bands by means of blanking dies in presses.

Cutting the stock by guillotine shears is shown schematically in Fig. 45. Three successive stages can be distinguished in this process:

(a) elastic deformation: the blade slightly compresses and bends the metal; the stresses do not exceed the yield point (Fig. 45*a*);

(b) plastic deformation: the stresses in the metal exceed the yield point and rise gradually reaching the ultimate shear strength (Fig. 45*b*);

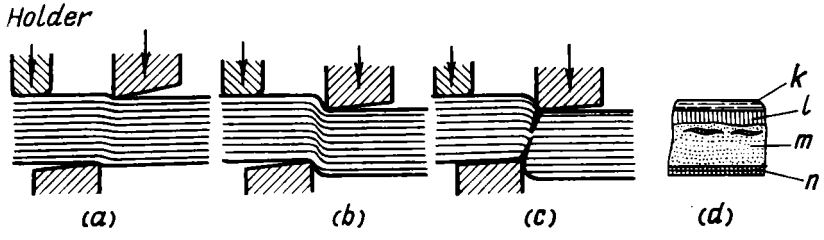


Fig. 45. Shearing sheet metal
k—zone of rounding; *l*—zone of cut; *m*—zone of shearing; *n*—zone of fracture

(c) failure: cracks are formed along the slide surfaces and the stock parts are separated (Fig. 45*c*).

After cutting, the edge of the stock clearly reveals two zones (Fig. 45*d*): a narrow bright belt corresponding to the plastic stage and a wider dull belt of the shear failure.

Die blanking of sheet metal. Die blanking and piercing of metal sheets is the most extensively used pressworking operation. This operation results in separation of one part of the stock from another, similarly to what happens in shearing, but closed contours can be obtained.

When the punch starts pressing into the stock, the latter bends down (Fig. 46*a*); stress concentrations near the cutting edges of the punch and the die cause the metal to flow and form zones of fracture. Such local fracture will proceed until stresses are adequate to produce sliding lines over the entire thickness of the stock. All this leads to shear accompanied by bending and tension, until shear cracks appear. Further forcing of the punch into the metal leads to shear cracks (Fig. 46*b*) appearing at the cutting edges of

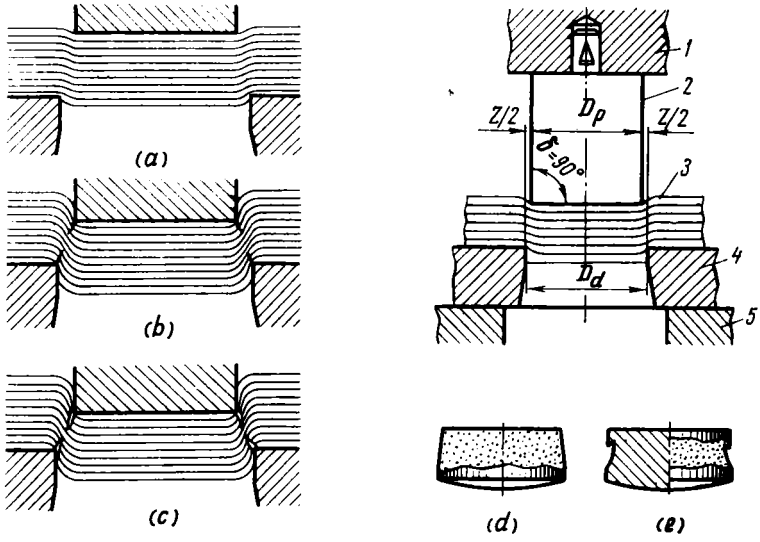


Fig. 46. Process of blanking

(*a*), (*b*), and (*c*) blanking stages; (*d*) normal finish of cut; (*e*) poor finish of cut; *1*—press slide; *2*—punch; *3*—work; *4*—die; *5*—press bed; D_p—punch diameter; D_d—die diameter; *z*/2—half clearance between punch and die; δ—angle of the punch cutting edge

the punch and die. These cracks are directed at an angle to the surface of the sheet; for them to meet, a certain clearance must be provided between the punch and the die.

After the shear cracks meet, the blanking contour separates (Fig. 46*c*). For the blanked piece or scrap after piercing to be removed, friction must be overcome between the surfaces of shear of the parts, as well as between the side surface of the piece being blanked (or the scrap in piercing operation) and the surface D_d of the die opening.

The force required for blanking or piercing operation is a function of the sheet thickness and mechanical properties, the cutting perimeter, the shape of the punch and die cutting edges (which can be flat or bevelled), the clearance between the punch and the die, and the condition of the cutting edges.

The formula for the pressure P required to punch or blank a given material, assuming the die and punch are flat, is

$P = SLT$, newtons, for any shape of aperture

$P = S\pi DT$, newtons, for round holes

where S = shear strength of material, pascals

L = sheared length, millimetres

D = diameter, millimetres

T = thickness of material, millimetres

The pressure to be developed by the press is taken to exceed the calculated force by 30 per cent to account for a nonuniform thickness of the stock, blunt cutting edges of the die, etc.

When using a spring, rubber, or air-actuated stripper, pad or ejector, the required pressure of the press will be a total of the blanking (or piercing) force and the force needed for compression of the buffer.

The blanking pressure will be the least with certain optimum clearances z for every particular kind of material being stamped and its thickness, when they cause the fractures, spreading from the punch and the die, to meet (Fig. 46*b*). This offers the best finish of the surface of cut with no burrs (Fig. 46*d*) and contributes to a longer life of the die.

With an insufficient clearance between the punch and the die, the shearing fractures will not meet, which will result in an uneven surface of the cut, and the formation of a double band (Fig. 46*e*).

The excessive clearance leads to tear-out of pieces and burr formation along the contour of the piece. The finish over the surface of the cut depends also on an even distribution of the clearance around the contour.

In blanking operations the clearance is provided by decreasing the size of the punch; in piercing this is done by increasing the die opening.

When piercing holes with smooth walls, smaller clearances are used. The best finish on the cut is obtained by strongly pressing the material with a holder and applying a small clearance.

For blanking and piercing of parts thinner than 0.3 millimetre use is made of dies without clearances. In this case, the working contour of a green die is obtained by broaching

it with a finished and hardened punch, or, alternatively, the working contour of a green punch can be obtained by drawing it through a finished and hardened die. The same technique is applied in making press tools for piercing small holes (with the diameter of the hole equal to, or smaller than, the thickness of the material).

Faulty surface of the cut and burrs can also result from blunt cutting edges of the punch and die. With the blunt cutting edges of the punch, the burrs arise along the contour of the part blanked; with the blunt edges of the die, the burrs appear around the hole made. Should both the punch and the die become dull, the burrs will be both on the part and around the hole on the work material.

When blanking thick material or large-size parts, the blanking and piercing force can be reduced by applying the press tools with symmetrically bevelled cutting edges in the dies (when blanking) or in the punches (when piercing). Owing to the bevel (usually referred to as shear), the blanking does not take place simultaneously over the entire contour, but proceeds gradually as the punch descends. This is why the blanking force, similar to the force of cutting by shears with an inclined top blade, will be much weaker than that developed when blanking by a press tool with parallel cutting edges. A shear must be at both sides and symmetrical with respect to the press tool pressure centre. This will eliminate lateral forces which may lead to dents on the cutting edges.

For blanking, the face of the punch is made flat and the die is sheared, as shown in Fig. 47 (*a* and *b*). This means that the stamping will be flat and the scrap curved.

For piercing, the die is made flat and the face of the punch (Fig. 47, *c* and *d*) is sheared. In this case, the stamping remains flat and the scrap knocked out of the die is curved.

The shear radically reduces (sometimes, halves) the blanking force as compared to the force required when using a non-sheared press tool.

To reduce the force in perforating (multiple-hole piercing), the punches are made of different length, as shown in Fig. 47*e*. The load acting upon the press is reduced owing to that the cutting forces arise at different times. When perforating heavy stock, the value of H is taken to be equal to

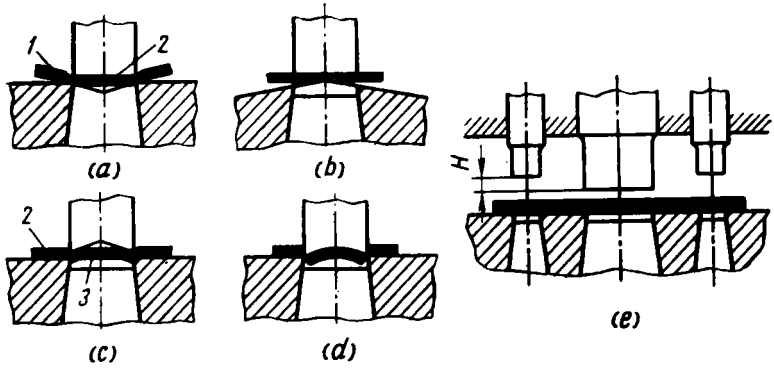


Fig. 47. Force reduction in blanking and piercing
(*a*) and (*b*) shear on die in blanking; (*c*) and (*d*) shear on punch in piercing; (*e*) pitched positioning of punches; *1*—strip; *2*—part; *3*—scrap

half the stock thickness, when piercing materials thinner than 2 millimetres, it is equal to the thickness of the material.

Shaving. The surfaces made by blanking or piercing are slightly tapered and rough. To obtain stampings of accurate sizes along the outside or inside contours, with sharp edges and smooth surface of cut normal to the piece surface, the operation of shaving is performed.

Shaving is cutting away the allowance. In this method, piece *2* (Fig. 48), blanked, straightened, and placed in the die, is forced by punch *1* into die *3* whose cutting edge gradually cuts the allowance off the workpiece.

Depending on the requirements extended to the surface finish of the cut and to the dimensional accuracy of the stamping, a single or repeated shaving operation may be performed. A single shaving is used for stampings thinner than 3 millimetres, having smooth contour lines. Repeated shaving is resorted to when stampings have right corners with no rounding-off or corners smaller than 90° with rounding-off of small radii, as well as for stampings thicker than 3 millimetres irrespective of their shape.

Shaving holes is similar to shaving along the outside contour except that the chips are not broken and escape in the form of a tube.

The surface finish of hard-steel stampings after shaving is as good as Class 6-7, the figure for soft steel and brass being Class 7-8. The Class of accuracy is 3.

The finish on the cut and shaving accuracy depend on the correct selection of the shaving allowance (0.1 to 0.4 millimetre, depending on the hardness and thickness of metal) and on the press tool accuracy.

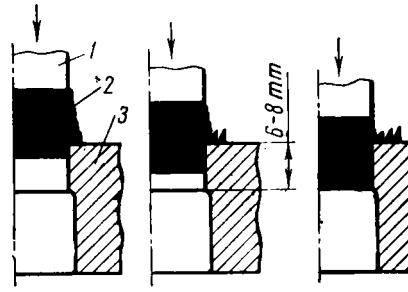


Fig. 48. Process of shaving
1—punch; *2*—piece; *3*—die

The clearance between the punch and the die in shaving is taken equal to 0.01 millimetre. The straight clearance in the die is 6-8 millimetres. The cutting edges of the die are rounded off with a radius of 0.2 millimetre.

When shaving the outside contour, the stamping is placed on the die with that side which faced it in the blanking operation. For shaving holes, the work is placed with its rounded-off edges facing the punch.

6.3. Bending Operations

Bending in dies is essentially a process whereby the working parts of the die exert pressure upon a flat blank to bend it and to impart it their shape.

Bending dies can produce parts of a great variety of shapes.

Figure 49*a* shows the sequence of bending operations. Throughout the process the blank has a fillet exceeding the corner radius of the punch with a gradual decrease of the curvature radius and the bending leg (l_0, l_1, l_2, l_f). In its gradually decreasing fillet the blank contacts against the female die walls at two points, and after a certain moment it is pressed against the punch at three points. It is only at the end of the stroke that the blank fully contacts the working surface of the punch and is finally shaped by the sizing blow.

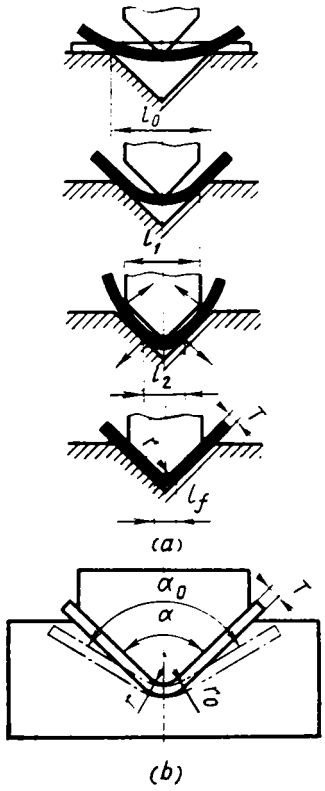


Fig. 49. Process of bending
(*a*) sequence of bending operations; (*b*) change in angle due to spring-back; l_0, l_1, l_2, l_f—gradual decrease of curvature radius and bending leg; r—punch radius; r_0—bend radius after spring-back; α—punch angle; α_0—angle of part after spring-back; T—stock thickness

Bending sheets or strips is a process of deformation which proceeds differently on the two sides of the blank being bent. In bending the concave side (that facing the punch) is compressed and the convex one (that facing the die) is tensioned. Between the compressed and tensioned parts there is a neutral axis which does not change in length.

In most cases, parts are bent with a small radius which is accompanied with thinning of the material in the straining zone. The thinning of the blank where it is bent depends on the ductility of the material, the degree of strain, and the bending angle.

The strains in the outside (convex) layers of the material, when bending to a small radius, can be so great as to cause cracks and even breaks in parts. To avoid this the bend radius should be selected to suit the material: from $0.5T$ for aluminium, brass, copper, 0.10%C steel, etc., to $1.5T$ for 0.6%C steel, duralumin, etc.

Bending develops elastic strains (spring-back of metal) owing to which the shape of a bent part differs from that of the punch and die. The degree of spring-back depends on many factors, mainly on mechanical properties of the stamping material, its thickness, the bend radius, and the method of bending.

Spring-back is measured as the difference between the angle α_0 of the stamping and the angle α of the punch in the bending die (Fig. 49*b*). A smaller bend radius means weaker spring-back.

The value of spring-back is usually found by testing the press tool and eliminated by finishing the punch.

Die bending can be performed either with or without a blankholder. Bending without a blankholder cannot preclude shifting of the blank and thus is used when high accuracy is of no importance. Bending with a blankholder precludes blank shifting, and the bent parts are thus adequately accurate. The most accurately bent parts are obtained with the aid of special guide holes which allow an accurate positioning of the blank in the die with no shift during bending.

Figure 50(*a* and *b*) shows methods of bending equal and unequal angles. If one flange is very short, the angle is bent in a press tool of the type shown in Fig. 50*c*.

For bending *Z*-shaped parts use is made of a press tool shown in Fig. 50*d*. For higher accuracy of bending the press tool can be provided with a blankholder (Fig. 50*e*).

Shallow channels up to 3 millimetres in thickness are bent in a single operation in the press tool shown in Fig. 50*f*, the die edges being rounded off. When bending blanks thicker than 3 millimetres, the die edges are bevelled to preclude indentation and thinning of material (Fig. 50*g*).

For bending deep channels, the punch is recessed at the working sides (Fig. 50*h*).

Channels with a curvilinear axis or of varying width are made in cam-actuated press tools (Fig. 50*i*).

Hat shapes up to 3 millimetres in thickness with sufficient bend radii ($2T$ to $3T$) are bent in a single operation in a press tool similar to the one shown in Fig. 50*j*. With thick material or small bend radii bending is performed in two operations as is shown in Fig. 50(*k* and *l*).

Curling and coiling-up is done by the pressure of the punch face with a semi-round recess. The edges of drawn or pressed parts are coiled up in press tools such as shown in Fig. 50*m*. At the initial contact between the punch and the blank the edge is bent; with the further stroke of the press slide the final coiling is done.

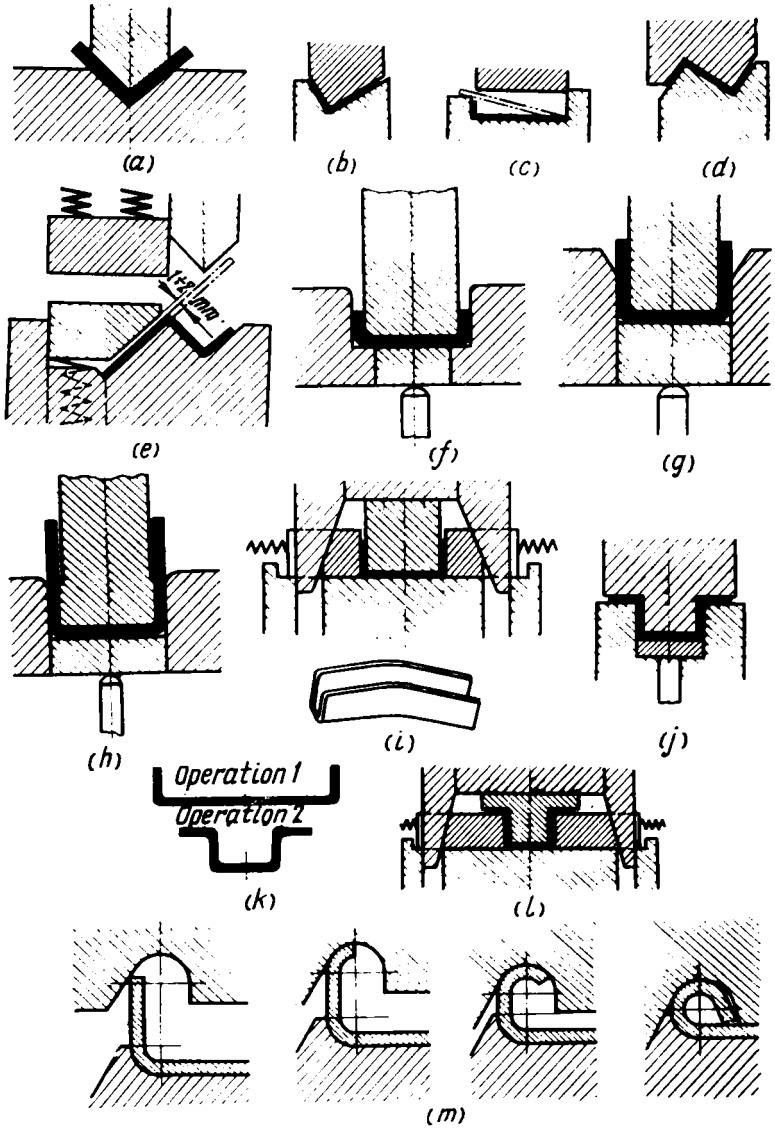


Fig. 50. Methods of bending typical parts

(*a*) equal angle; (*b*) unequal angle; (*c*) short-flange angle; (*d*) Z-shape (no blankholder); (*e*) Z-shape (blankholder used); (*f*) shallow channel ($T \leqslant 3$ mm); (*g*) shallow channel ($T > 3$ mm); (*h*) deep channel; (*i*) irregular channel; (*j*), (*k*), and (*l*) hat shapes; (*m*) curling and coiling-up in one operation

6.4. Drawing Operations

Drawing is a process in which a punch causes flat metal to flow into a die cavity to assume the shape of a seamless hollow vessel. Obtaining hollow vessels of different shapes from hollow stampings is known as a *redrawing*.

Drawing can be done without wall thinning or, on the contrary, so that the wall thickness is reduced. The latter process is referred to as ironing.

Drawing without wall thinning. Figure 51*a* is a schematic representation of drawing a cylindrical cup from a flat blank. In this operation (called also cupping), the circular portion of the blank, lying between the diameters D and d, turns into a cylinder of a diameter d and a height h_1. The increase in height is due to displacement of metal. The metal displaced is conventionally shown by hatched triangles. Since in drawing the volume of metal does not change, the cup height h_1 is larger than the width h of the circular portion of the blank.

In deep drawing, the displaced (excessive) volume of metal forms wrinkles (Fig. 51*b*). A hollow part with no wrinkles can be obtained only by drawing of blanks in which the difference between the diameter of the blank and that of the cylinder is relatively small. This means that a single drawing operation gives rather shallow parts. To prevent wrinkling, the blank, prior to drawing, is pressed against the face of the die by a special blankholder.

Drawing can be performed in several stages, gradually reducing the diameter and increasing the height of the part being drawn (Fig. 51*c*); the number of stages depends upon the shell height-to-diameter ratio and upon the relative thickness of the blank.

The stock being drawn flows over the edge of the die. Therefore, the radius of the draw ring* of the die influences the stresses arising in the stock, the drawing pressure, the stock thinning, wrinkling and rupturing, as well as the severity of draw.

The *severity of draw* is the ratio of the final part diameter d to the initial blank diameter D.

* Draw ring is a ring-shaped die part, over the inner edge of which the metal is drawn by the punch.

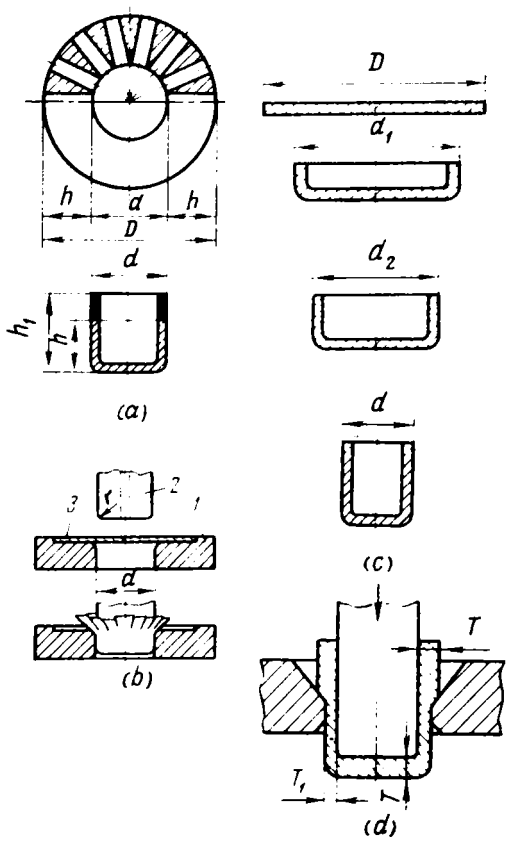


Fig. 51. Process of drawing

(*a*), (*b*), and (*c*) drawing without wall thinning; (*d*) ironing; *1*—die; *2*—punch *3*—blank; *D*—steel blank diameter; *d*—part diameter; d_1, d_2—part diameters after brawing stages; *h*—part height; h_1—height of drawn part; *T*—stock thickness; T_1—thickness of part wall; *r*—punch-nose radius

Greater draw radii mean lighter stresses in the stock and less thinning of the blank walls. However, too great a draw radius may cause wrinkles. The draw radii corresponding to the drawing depth and stock thickness are found by trial.

The *punch-nose radius* is chosen, whenever possible, to be equal to the draw radius, but it can also be taken much smaller to suit the required shape of the drawpiece. The smallest permissible punch-nose radius equals double thickness of the stock being drawn, since too small radius on the punch causes considerable thinning of the stock.

The clearance between the drawing punch and die should be equal to the maximum permissible thickness of the draw stock plus extra clearance for the thickening of the blank edge due to drawing. For the final (sizing) stage in the drawing of parts with the external dimensions specified, the clearance is made at the expense of the punch, in the drawing of parts with the internal dimensions specified, at the expense of the die. In all draws except the sizing one, the direction of the clearance is of no consequence.

The blankholding force is essential: an excessive force intensifies the stock thinning and sometimes may cause the bottom to break off from the part, while an inadequate force leads to wrinkling. When the wrinkles are smoothed down, the drawing force between the punch and the die grows sharply and tears the bottom off. The force of blankholding is checked and adjusted when testing the press tool.

Cold drawing causes metal to harden. The work-hardened metal loses much of its ductility and toughness. To relieve the work-hardening effects, parts are annealed between draws.

Ironing. It is a method of redrawing in which the part thickness is intentionally reduced to a predetermined value with a minor reduction in diameter, which leads to a considerable lengthening of the part.

The process of ironing is diagrammed in Fig. 51*d*. The number of ironing draws depends upon the permissible strain factor, calculated or found from reference tables. In making thin-walled sleeves, the part is drawn through two or three dies in succession, gradually reducing the thickness of its walls.

Irrespective of the number of draws and the degree of wall thinning, the thickness of the part bottom remains equal to the original thickness of the blank (T).

The punch-to-die clearance z is found for each particular draw. For the first draw it must allow for the permissible variation in blank thickness, but in any case it is smaller than the blank thickness and corresponds to the chosen degree of strain.

6.5. Forming Operations

Embossing produces relatively shallow indentations or raised designs by stretching and partial dislocation of material. The possibility of embossing without the breaks in material is determined by the relative elongation of the material in the zone of maximum deformation.

The most popular applications of embossing are for forming stiffener ribs and depressions (Fig. 52).

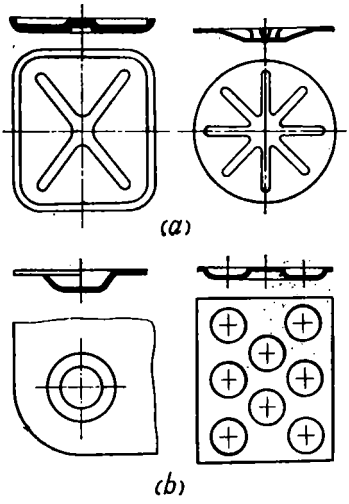


Fig. 52. Examples of embossing
(a) stiffener ribs; (b) depressions

Flanging is an operation by means of which flanges are made along the outer contour of a piece or the edges of pierced holes. Figure 53*a* shows hole flanging operations.

For obtaining a high flange on large holes or when performing progressive stamping on a strip, which cannot be done in a single operation, first a drawing operation is done, then a hole is pierced in the bottom, and finally a combined drawing and flanging operation is accomplished (Fig. 53*b*).

For obtaining high flanges on small-diameter holes in individual workpieces, flanging with reduction of wall thickness is done by a multistepped punch (Fig. 53*c*).

For obtaining low flanges

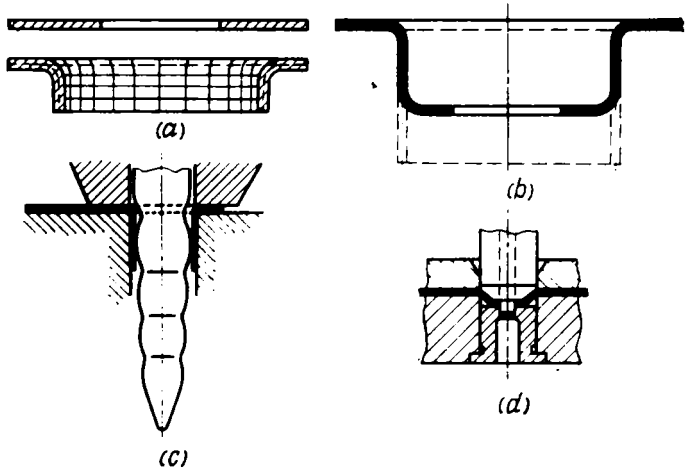


Fig. 53. Process of flanging
(*a*) general diagram of flanging process; (*b*) making high flanges on a drawn part; (*c*) making high flanges by stepped punch; (*d*) dimpling and piercing of holes

(for instance, in dimpling, i.e., forming a recess for a flush-head fastener), the punches accomplish a simultaneous combined flanging, drawing, and piercing of a hole (Fig. 53*d*).

The quality of flanging operation is largely dependent upon the corner radius of the die port, the punch shape, and the punch-to-die clearance.

The larger die-edge radius, the easier it is to obtain a higher flange.

Experience shows that an increased punch-to-die clearance results in a natural increase of the corner radius and flange height.

Trueing is used for smoothing the work surface or for correcting the curvature of stampings. Trueing is often accompanied with sizing to improve the dimensional accuracy of stampings. Drawn, flanged, and bent parts are trued mainly for reducing the bend radii and correcting the bottoms and sides. Trueing requires considerable pressures and therefore is performed in coining and friction presses.

Flat stampings up to 1 millimetre thick are straightened in plain dies between the surfaces of the ram and bolster plates (Fig. 54*a*). Thicker stock, on whose surface minor imprints can be tolerated, is straightened by means of waffle dies (Fig. 54*b* and *c*) with crisscross or waffle design

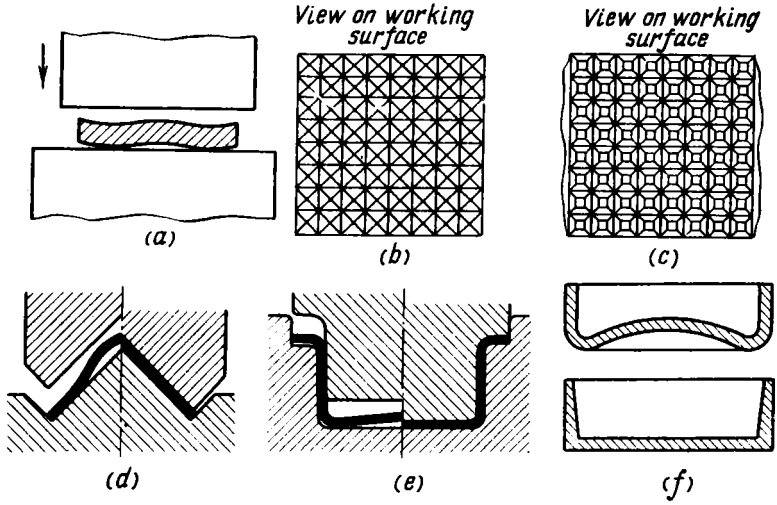


Fig. 54. Trueing and sizing of stampings
(*a*) straightening in plain die; (*b*) and (*c*) waffle dies; (*d*) sizing of angle; (*e*) sizing of bracket; (*f*) sizing of cup with sharp corners

on the surface. In straightening, it is necessary to position the press tool so that the teeth of the ram plate are dead opposite the valleys in the bolster plate.

Figure 54 (*d* and *e*) shows the process of trueing bent parts and sizing their flanges. Figure 54*f* is a diagram of making a hollow part without rounding in the corners. The part is made in two operations: drawing a cup with a concave bottom and trueing together with sizing sharp corners.

6.6. Compression Operations

Compression is used for making small-size and intricately shaped parts of highly plastic metals. The process is similar to forging. However, since the work is not heated, the stampings are more accurate and have a better surface finish. Compression employed in conjunction with other

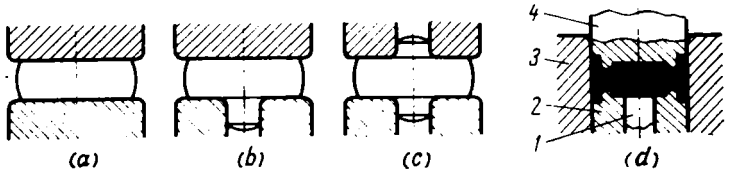


Fig. 55. Process of swaging

(*a*) swaging between flat die plates; (*b*) swaging with flow to the bottom annular plate; (*c*) swaging with flow to the bottom and top annular plates; (*d*) swaging in closed die; *1*—ejector; *2*—die; *3*—die ring; *4*—punch

stamping operations yields stampings that require little or no machining.

Compression operations may be divided into the following: swaging, cold extrusion, upsetting, sizing, and lettering.

Swaging is the most frequently used compression operation. Its simplest version is aimed at flattening the work or at making parts with single-sided or double-sided projections (Fig. 55). The metal being swaged freely flows in the radial direction and fills in the cavities in the top and/or bottom dies.

Swaging is also used for making intricately shaped parts in high-precision dies with shaped cavities. Work hardening in the process of swaging increases the strength and hardness of the parts. Surface finish of such parts is within Class 7 and their sizes are accurate to Class 5. Figure 55*d* presents an example of part swaging.

Two methods of swaging are known: (1) in open dies where excessive metal is squeezed as flash into the clearance between the top and bottom dies and (2) in closed dies, without any burrs.

Open-die swaging requires an additional operation of trimming off the flash, but it is not necessary to keep the blank to the accurate size. The dimensional accuracy of parts made in closed dies depends on how accurately the blank was made. Swaging dies are made massive and with the forming impressions of adequate accuracy and good finish. Parts of high precision and intricate shape call for two dies: one for pre-forming and the other for sizing.

The surface roughness of swaged parts depends upon the blank roughness, so the latter should be carefully cleaned off scale, rust, and foreign objects prior to forming.

Cold extrusion consists essentially in that the metal, upon which high pressure is exerted, becomes plastic and flows into the die-to-punch clearance.

As compared to drawing, cold extrusion is advantageous in that it allows making thin-walled parts with intricately shaped bottoms while enjoying a higher efficiency of metal utilization, larger output, and lower die cost.

To lend itself well to cold extrusion, a metal must be very ductile, possess low ultimate strength, and show little tendency to work hardening.

Two methods of extrusion are normally employed: forward, in which the metal flows in the direction of the punch working stroke (Fig. 56, *I*), and backward, wherein the metal flows in the direction opposite to the motion of the punch (Fig. 56, *II*). Use is also made of opposed extrusion (Fig. 56, *III*) in which the metal simultaneously flows in, and opposite to, the direction of the working stroke of the punch.

Forward extrusion is used for making flanged parts, as well as rod-like and tube-like parts of various cross sections; backward extrusion is good for making hollow parts with cup-type bottoms; opposed extrusion is applicable to intricately shaped parts with shoulders and ribs in the bottoms, as well as parts with two cavities and a web between them.

Used as blanks for forward extrusion are flat washers or thick-walled cups (Fig. 56*b*). Backward extrusion uses billets in the form of solid parts finish-blanked from a metal sheet or cut from a bar. The shape of the blank should correspond to that of the part cross section.

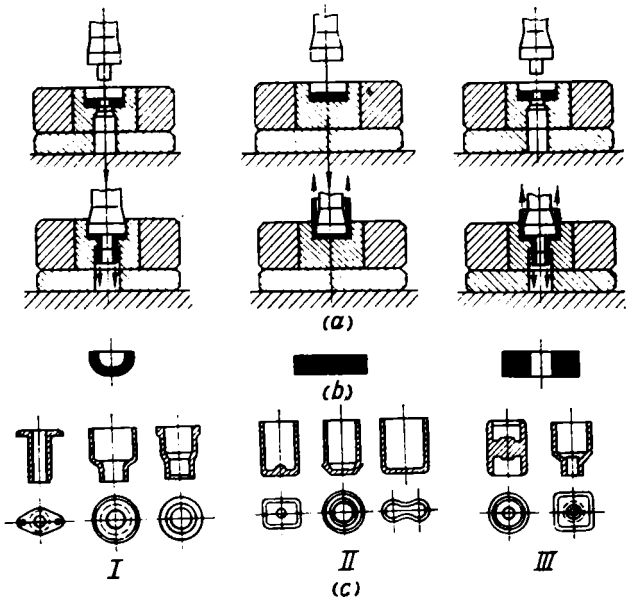


Fig. 56. Cold extrusion
I—forward; *II*—backward; *III*—opposed; (*a*) diagrams of process; (*b*) blank shapes; (*c*) products

Cold extrusion is used for making parts from lead, aluminium, zinc, copper, brass, and low-carbon steel.

Cold heading is the process of upsetting the ends of bar, wire, or the tube stock while cold. Cold heading is used for shaping nuts, the heads of rivets, bolts, screws, wood screws, as well as some machine components made from steel or non-ferrous metals. Cold heading is employed in manufacturing bolts up to 20 millimetres and nuts up to 27 millimetres in diameter.

The operations of cold heading are usually performed on automatic single-, double-, and triple-stroke cold headers. The parts obtained by cold heading are made from wire or bars of the required cross section. Round-head rivets and screws and other parts with the headed section of relatively small length are made in one stroke.

The single-stroke heading of a rivet proceeds as follows. After the stock (sized wire) has been fed through the cut-off die, the blade of the machine cuts off the blank and transfers it to the heading station. The heading punch pushes the blank into the die to contact with the knockout and then it performs the heading operation. As the punch returns into its initial position, the headed part is removed from the die by the knockout and the cycle starts again.

Double-stroke heading allows various shape heads to be obtained by upsetting a blank length equal to 3-6 diameters of the wire.

The shape most suitable for gathering the metal is a truncated cone. Figure 57 shows the process of double-stroke heading.

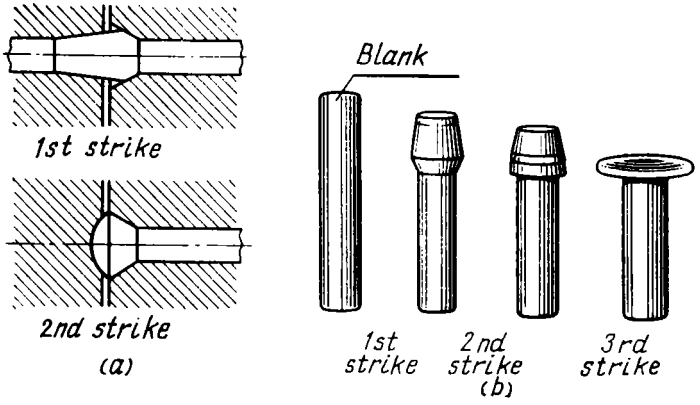


Fig. 57. Process of double-stroke cold heading
(a) oval-head screw made in double-stroke header; (b) valve push rod made on triple-stroke header

Sizing is performed to obtain dimensional accuracy and high surface finish on parts made by swaging or press forging. Sizing is done in dies on impact-type (friction or coining) presses. Sizing can be either flat or three-dimensional.

In *flat sizing*, only certain planes of the blank are squeezed and sized in thickness (Fig. 58*a*). The squeezing factor is usually from 5 to 10 per cent of the original blank thickness.

Three-dimensional sizing involves all-round squeezing of the blank, forcing the metal into the flash which is subsequently removed by cutting off or shaving (Fig. 58*b*).

In some cases, the parts are first subjected to three-dimensional and then flat, sizing; this is known as *combination sizing.*

Cold sizing of forgings and other workpieces ensures accuracy within 0.05 millimetre and surface roughness of Class 7 or 8 (comparable to finish grinding). The accuracy and quality of sized parts depend on the accuracy of the die and the finish of its sizing surfaces.

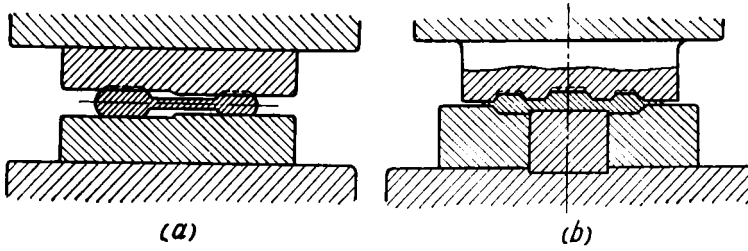


Fig. 58. Sizing
(*a*) flat; (*b*) three-dimensional

Coining produces an impressed raised design on the part surface by slight redistribution of the metal. The operation can in many cases substitute for engraving on metal parts. In coining, the workpiece is compressed between the two forming sections of a die which imprints its design on the workpiece surface. To retain the size and shape of the work, coining is usually performed in closed dies, without forcing metal out of the female die working cavity. The process is performed on coining presses which can provide high pressures and accurate adjustment of the clearance between the punch face and female die bottom.

Lettering or embossing letters, figures, and graduation lines is similar to coining.

Chapter 7

Pressworking Equipment

7.1. Presses

All operations described in the preceding chapter are performed in presses. Depending on the working conditions and the nature of parts to be made, different types of presses can be selected.

A press may have a mechanical, hydraulic, pneumatic, electromagnetic, or manual drive. Pressworking practice usually employs mechanical and hydraulic presses; pneumatic, electromagnetic, and manual presses find application mainly in press-fitting and assembly operations.

With respect to the action upon the material being stamped, mechanical, and hydraulic presses are further classified into single-action, double-action, and triple-action ones.

A *single-action press* has only one slide. These machines are employed for various pressworking operations, such as blanking, piercing, bending, shallow drawing, forming, etc.

A *double-action press* has two slides arranged one within the other and moving independently of each other. The outer slide generally serves for blankholding, while the inner one carries the punch. Double-action presses are mainly used for drawing sheet metal, but they are also good for forming and cutting operations.

A *triple-action press* incorporates three slides, two of which are located above and one within the bed. Such presses are used for complicated deep-drawing operations on sheet metal. Figure 59 shows the operation of single-, double-, and triple-action presses.

The most popular single-action presses are *crank and eccentric* types. They can have one, two, or four cranks.

Single-crank presses are subdivided into gap-frame and straight-side types. In gap-frame presses, the crank and leverage are arranged on the overhanging end of the working shaft. Since such machines are open both from the front and the sides, they permit feeding metal strips as well as individual blanks. However they have a limited rigidity, which

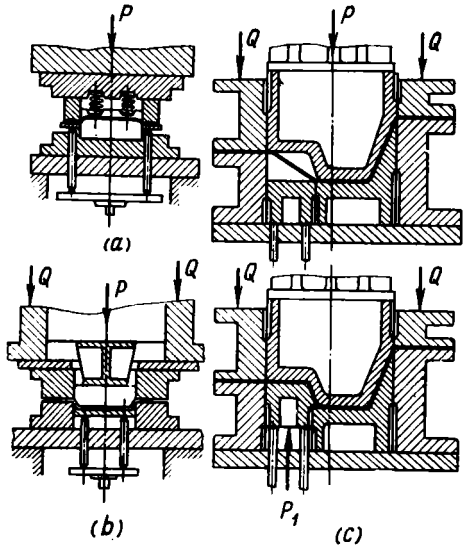


Fig. 59. Pressworking in presses of different types
(a) single-action press; (b) double-action press; (c) triple-action press; P—upward pressing force; P_1—downward pressing force; Q—blankholding force

leads to notable springing of the frame during operation. This is why gap-frame presses are not good for making precision parts.

Figure 60 shows a diagram of a gap-frame eccentric press. Flywheel *7* is rotated from the shaft of electric motor *8*. When clutch *6* is engaged by means of treadle *1*, main shaft *5* rotated by the handwheel drives pitman *3*. This makes slide *2*, hinged to the pitman, reciprocate and perform the stamping operation. Brake *4* eliminates the inertia of the rotating main shaft, thus bringing the slide to halt in its uppermost position after the clutch has been disengaged.

Flywheel *7* is intended for accumulating kinetic energy. During the working stroke, the flywheel transfers some of its stored energy to the workpiece and compensates for the loss with the aid of the electric motor.

One of the advantages of eccentric presses is that their slide stroke can be easily adjusted by turning the bushing

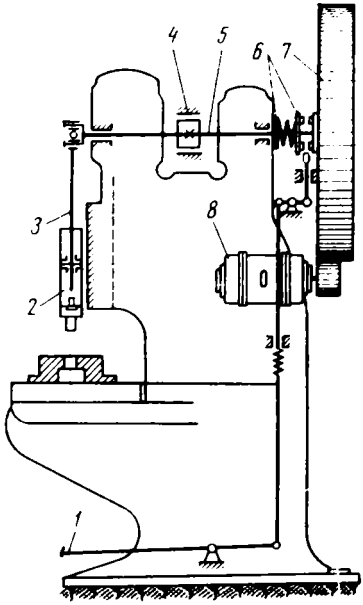


Fig. 60. Single-action gap-frame crank press

1—treadle; *2*—slide; *3*—pitman; *4*—brake; *5*—main shaft; *6*—clutch; *7*—flywheel; *8*—electric motor

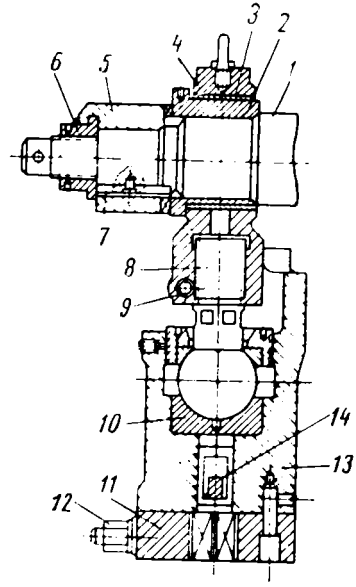


Fig. 61. Slide adjuster

1—crankshaft; *2*—eccentric bushing; *3*—bronze bushing; *4*—pitman; *5*—lock clutch; *6*—nut; *7*—key; *8*—screw; *9*—slide block; *10*—spherical bearing; *11*—clamp; *12*—nut; *13*—slide; *14*—pusher

of the pitman head on the shaft cam. This cannot be done in most of crank presses, since their typical design provides for a direct connection of the pitman head with the shaft journal.

In gap-frame crank presses the bearings of the crankshaft are on one side of the pitman, while in straight-side presses the pitman is arranged between the crankshaft bearings.

The rotation of the shaft is converted into the reciprocation of the slide by the crank-and-pitman assembly. The crankshaft rotation determines the lowermost and uppermost positions of the slide. The distance between the terminal points of the slide motion is referred to as *slide*

stroke. One revolution of the crankshaft corresponds to two strokes of the slide, one downwards and one upwards. The stamping operation is performed only when the slide descends.

In gap-frame crank presses up to 100 tons, the slide stroke may be either constant or adjustable. The slide adjuster (Fig. 61) is designed as follows.

The overhanging end of crankshaft *1* carries eccentric bushing *2* and bronze bushing *3*; the latter enters in the cavity of the head of pitman *4*. The eccentric bushing has blind holes drilled over its circumference. If a forcer is inserted into these holes, it becomes possible to turn the bushing around shaft *1*. Turning the bushing changes the eccentricity of the crank and, consequently, the slide stroke. Spontaneous turning of bushing *2* is prevented by lock clutch *5* whose projections engage depressions in the bushing. The front end of the crankshaft is threaded to receive screw nut *6* whose shoulder connects it with the lock clutch. When being unscrewed, the nut shoulder will draw the lock clutch away from its place and thereby disengage clutch *5* and bushing *2*. After this, bushing *2* is free for adjustment by turning it through the required angle. Clutch *5* is connected with shaft *1* by key *7*.

The maximum slide stroke is equal to the sum of eccentricities of bushing *2* and the shaft. The slide stroke is minimized by setting the eccentricity of bushing *2* strictly opposite to the eccentricity of the shaft (in this case, the slide stroke is equal to the difference of the eccentricities of the shaft and the bushing). The distance from the bed to the lower plane of the slide is adjusted by screw *8* screwed into the shank of pitman *4* and resting against spherical bearing *10*. The adjusted screw is fixed in position by slide block *9*. The shank of the punch is secured by clamps *11* with the aid of nuts *12*.

For blank removal from the punch, slide *13* has a hole that can permit a round rod contacting pusher *14* to pass. The pusher can travel in the port of the slide. When the slide ascends, the pusher ends touch upon rests attached to the press bed.

Any overload influences first the pitman. Therefore, protective washer *3* is placed on support ring *2* installed either

under step bearing *1* (Fig. 62*a*) or under the end of the cylindrical boss, depending on the design of the pitman. The protective washer fails in shear (Fig. 62*b*) if the press is overloaded, but it can be easily replaced after removing cover *4* (Fig. 62*c*).

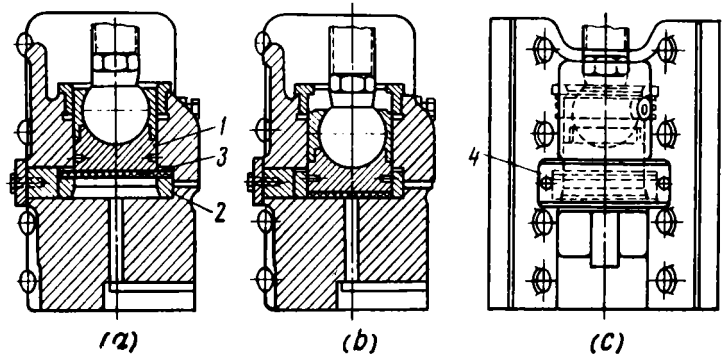


Fig. 62. Shear-type safety devices
1—step bearing; *2*—support ring; *3*—protective washer; *4*—cover

To hold the blank in drawing or bending and to knock out the parts from the bottom part of the die, provision is made of cushions (Fig. 63) normally attached to the bottom of the press beneath the table. The cushions may be of spring, rubber, pneumatic, hydropneumatic, and hydraulic types.

Presses up to 100-ton capacity are usually equipped with spring or rubber cushions. They are simple in design, but their resistance grows with compression. This means that by the end of the stroke the blankholding pressure or the knocking-out force is much higher than at the beginning of the operation.

The pneumatic, hydropneumatic, and hydraulic cushions ensure constant blankholding pressures or knocking-out force during operation. Besides, they are often used for actuating different units of press tools.

The suspension-type pneumatic cushion shown in Fig. 63*c* has two fixed air-operated cylinders *1* whose pistons *2*

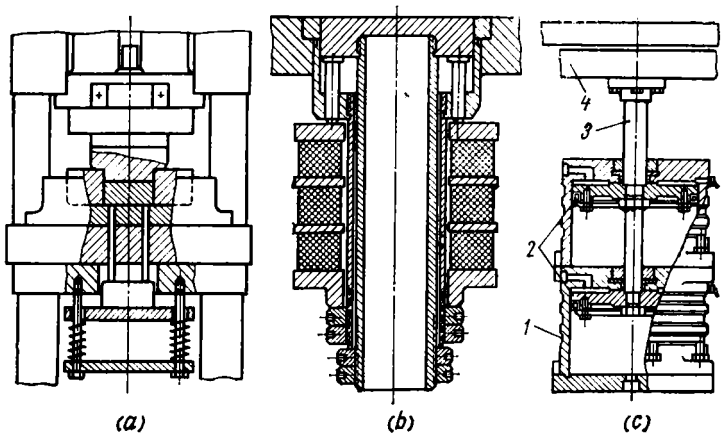


Fig. 63. Cushions for mechanical presses
(*a*) spring cushion; (*b*) rubber cushion; (*c*) suspension-type pneumatic cushion; *1*—air-operated cylinders; *2*—pistons; *3*—common rod; *4*—plate]

are interconnected by common rod *3*. Compressed air fed under the pistons forces the press table and, via it, plate *4* that passes through an opening in the table and carries the press pushers.

Friction presses are employed for forming bending, sizing, and trueing sheet metal parts, as well as for bending pipes and profiled stock. In the absence of crank presses they may be employed for drawing, blanking, and piercing operations. However the dies used for these purposes in friction presses differ considerably from those used for the same work in crank presses.

Friction presses find a wide application in forging. They can be of a double-, triple- or no-disc design.

Figure 64 shows the design of a double-disc press. Electric motor *3* drives shaft *6* via V-belt or gearing *4*. The shaft carries two massive discs *5* of cast iron (upstroke and downstroke discs). Arranged between the discs and set on the end of working screw *10* is flywheel *7* coated with leather (or another friction material). The screw rotates in a nut fixed at the top of frame *17*. The bottom end of the screw carries slide *15* and pusher *1*, travelling vertically

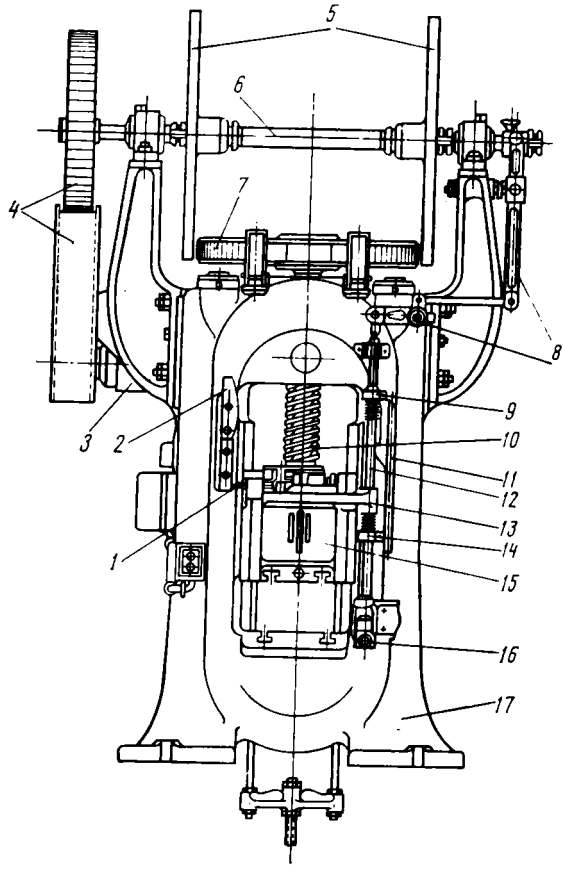


Fig. 64. Double-disc friction press

1—pusher; *2*—camp gib; *3*—electric motor; *4*—gearing; *5*—discs; *6*—shaft; *7*—flywheel; *8*—levers; *9*—top clamp; *10*—screw; *11*—catch; *12*—tie rod; *13*—switch; *14*—bottom clamp; *15*—slide; *16*—control lever; *17*—frame

in the guides of frame *17* provided with brakes in the form of cam gibs *2*. Levers *8* shift shaft *6* together with the friction discs to the right and to the left. This brings flywheel *7* into frictional engagement with the right or left disc alternatively. The flywheel, consequently, turns either to the right or to the left. At the same time, screw *10* travels

up and down, and so does slide *15* together with the upper die section attached to it.

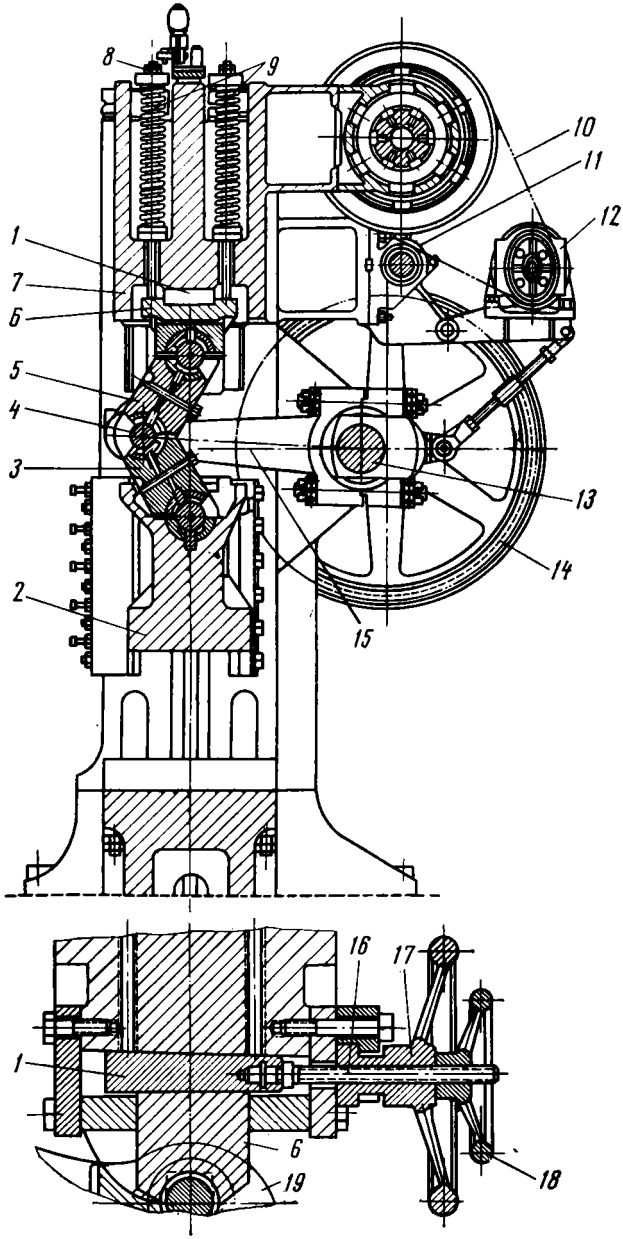
The press is controlled by means of lever *16*. The lever cannot be manipulated unless the operator's left hand pushes away safety catch *11* and thus releases switch *13*. At the end of the slide downstroke, lever *16* is released, which is aided by bottom clamp *14*. The stroke of the slide and the flywheel is limited by top clamp *9* secured on tie rod *12* with a safety catch. As soon as the ascending slide lifts the top clamp and, thereby, tie rod *12*, the levers move the lifting disc away from the flywheel. The flywheel goes on rotating, lifts the slide, and, due to this, lows down. The final stop is accomplished by means of a band brake.

Triple-disc friction presses differ from the double-disc design in that they have no lifting disc, but are provided, instead, with two discs having tooth rims engaging each other. This precludes slipping and wear of the discs and of the flywheel friction band.

No-disc friction presses are the most efficient ones. In such presses, the rotation of the electric motor is transmitted to the flywheel through a friction roll set on a shaft with a friction clutch, the roll engaging the inside surface of the flywheel. The speed of the flywheel rotation and, consequently, that of the screw and slide travel is the same for the downstroke and upstroke. The press is hand-controlled by means of rods.

Coining presses are applicable to such compression operations (forming, straightening, sizing, coining, and the like) which call for high pressures, but short strokes of the press. Articles made in these machines are very accurate thanks to the fact that the frames of such presses are massive and their guides are long; besides, such presses have a special method of actuation with a knuckle joint which makes it possible to increase the pressure at the end of the stroke.

Figure 65 shows the diagram of a knuckle-joint coining press. Crankshaft *13* is rotated by the shaft of electric motor *12* via V-belt *10* and gearing *11*. Large gear *14* is freely set on the crankshaft and connected with it by an engagement clutch. When the press is started, crankshaft *13* transmits the motion to pitman *15* connected, via axle *4*, with levers *5* and *3*. Lever *5* is hinged to top support *6*, and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18

lever *3* to slide *2*. When the pitman moves, the knuckle-joint levers first align and send the slide down, then they "break", i.e., turn at an angle to one another, and raise the slide. Top support *6* is fastened to frame *7* by bolts *8* with springs *9*. Installed between the frame and the inclined top plane of support *6* is wedge *1* which serves for adjusting the shut wedge height of the die space available for mounting the die. The position is controlled by a screw which changes the shut height by 7 to 15 millimetres.

The shut height adjuster is shown in the same figure. Wedge *1* is moved to the right or left by screw *16* and handwheel *17* which is rotated by hand. This lifts or lowers top support *6* of knuckle-joint drive *19*. The wedge is locked in the chosen position by handwheel *18* acting as a locknut.

Knuckle-joint presses are equipped with lever-actuated top and bottom knockouts. The top knockout acts similarly to the knockouts of crank presses, while the bottom one is driven from the crankshaft via a leverage.

Overloads are very dangerous for knuckle-joined presses. Therefore, modern knuckle-joint presses are equipped with instruments that indicate the actual pressure developed in operation. These instruments are used in press adjustment and operation.

Hydraulic presses (Fig. 66) are employed for forming, blanking, and drawing in small-lot and serial production. Hydraulic presses are superior to mechanical ones in drawing operations because they ensure drawing rate control and a uniform blankholding. Besides they are insensitive to overloads that often cause failures of mechanically-driven presses; the force developed by the press does not depend upon the position of the slide and remains constant throughout the entire stroke; the working tool delivers no impact on the blank when contacting it. An important advantage

Fig. 65. Knuckle-joint coining press

1—wedge; *2*—slide; *3*, *5*—knuckle-joint levers; *4*—axle; *6*—top support; *7*—frame; *8*—bolts; *9*—springs; *10*—V-belt transmission; *11*—gearing; *12*—electric motor; *13*—crankshaft; *14*—gear; *15*—pitman; *16*—lead screw; *17*, *18*—handwheels; *19*—knuckle-joint drive

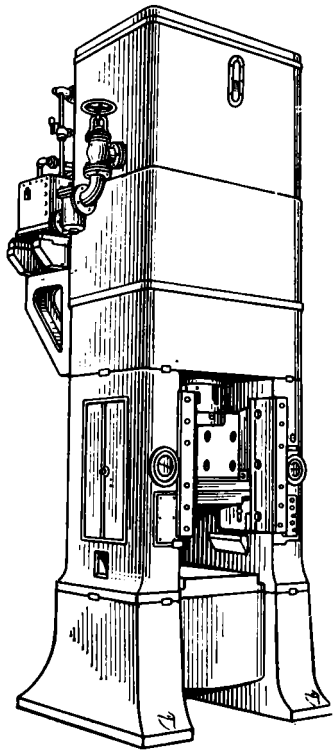


Fig. 66. Hydraulic drawing press

of hydraulic presses is the possibility to control the shut height of the press and the slide stroke.

Hydraulic presses are classified into those of single-, double-, and triple-action. They may all be driven from a central hydraulic accumulator fed by a pump, or have individual drives from one or more pumps.

In double-action presses, the outer working slide and the drawing slide travelling inside it can move either jointly or independently. The lower table of triple-action presses has one or several drawing cushions driven from an individual hydraulic pump which is independent of the main drive of the cross bar travel. Operation of such presses requires strong blankholding in order to avoid wrinkling.

In sheet-stamping hydraulic presses, the die space is considerably larger than in presses of other types, which allows handling large-size blanks. The tonnage of these presses is very high, from 150 to 2000 tons and over.

7.2. Press Dimensions and Performance Characteristics

A press can be specified in terms of a number of dimensions (Fig. 67) and characteristics.

Press tonnage P is the maximum pressure that can be applied to the slide without affecting the structural strength

of the press with the crank turned through an angle of not more than 30° from the bottom zero position.

In double-action crank presses the tonnage of the inner slide determines the maximum drawing pressure, while the maximum blankholding pressure depends on the tonnage of the outer slide.

Slide stroke h is the distance between the topmost and owermost positions of the slide, i.e., the path covered by

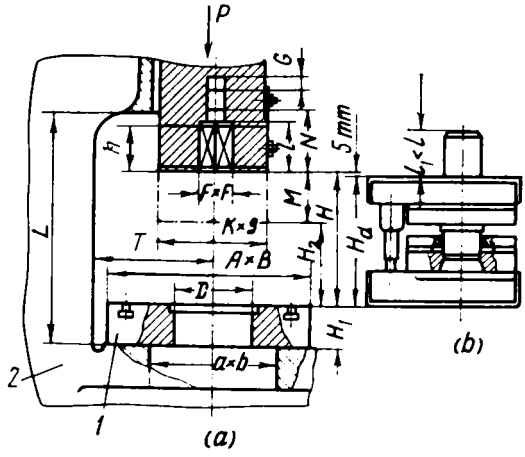


Fig. 67. Dimensions of press (*a*) and die (*b*)
1—bolster plate; *2*—frame

the slide in half revolution of the shaft. In some presses the stroke, can be adjusted by turning an eccentric bushing. If this is the case, the maximum slide stroke is equal to twice the sum of eccentricities of the bushing and the shaft, and the minimum, to twice their difference. With the bushing set so that its maximum eccentricity coincides with the maximum eccentricity of the shaft, the result is the maximum stroke.

The press certificate normally indicates the maximum, minimum, and intermediate strokes obtainable in a given

press. The stroke value governs the types of operation that can be performed on the press.

The *number n of strokes per minute* is necessary for calculating the slide speed and the press output. Press certificates indicate strokes per minute at the continuous running speed.

The *range of pitman-length adjustment M*, which is the difference between the maximum and minimum lengths of the pitman, determines the variability of the shut height of the press.

The *maximum shut height H* of a press is the distance from the top of the bed to the bottom of the slide with the stroke down and adjustment up. The shut height can be found under any stroke by adding the shut height shown in the certificate to half difference between the maximum stroke and the stroke under which the shut height is determined.

The *minimum shut height* H_2 of a press is the difference between H and M.

The *distance between the press table and the guides* is denoted by the letter L.

The *throat depth T* is the distance from the slide centreline to the frame; it determines the maximum distance between the shank axis and the rearmost point of a die that can be mounted on the press.

The *size of the slide* $K \cdot S$ and *of the table* (or bolster plate) $A \cdot B$ (K and A denote width, S and B, depth) is used for determining the overall dimensions of dies which can be mounted in a given press.

The *size of the openings in the table*, $a \cdot b$ and *in the bolster plate D* allows the blanked part to drop through, or a cushion to be withdrawn and set up

The *size of the square opening in the slide* $F \cdot F \cdot l$ (cross section by depth) determines the size of the attachment shank on the upper part of the die.

Dimension G determines the *maximum stroke of the upper knockout* which is indicative of the possible draw of a shell drawn with the bottom up.

Dimension N is the *distance between the knockout and the lower face* of the slide.

The *bolster thickness* H_1 is subtracted from the certificate-indicated press shut height to determine the permissible height of a die mounted on the bolster plate.

The *die height* H_d is usually determined with the die in its lower working position, since it allows the best interaction between the upper and the lower working parts of the die, as well as between its holding and removing parts. The die height should not exceed the shut height of the press.

For practical purposes, the die height (in the lower working position) should lie between the maximum (H) and the minimum (H_2) shut heights of the press. Figure 67 conventionally represents the minimum clearance of 5 millimetres between H and H_d. If the die height is considerably less than H_2, it is necessary to use spacer plates or blocks placed under the die shoe.

Chapter 8

Die Design in Pressworking

8.1. General Design Features and Classification of Dies

Dies are classified according to their *application*, design features, methods of blank feeding, and scrap ejection.

With respect to application, all dies fall into cutting and shaping dies.

The former include dies for shearing, blanking, piercing, notching, trimming, and shaving; the latter are those used in bending, forming, drawing, compression, and other operations.

Classification according to applications covers the number of operations that can be performed by means of one die, grouping press tools under the headings of plain (single-operation), combination (multioperation), and progressive (multistation) dies.

With respect to *design* the dies are divided into those without guides, those with a heel block, and those with guide posts.

According to the *method of blank feeding* dies can be designed either for manual or automatic feed, the *method of removing finished parts* allows a division of dies into those with a hole through which the part drops, the ones in which

the work is ejected upwards and then removed by a positive knockout, and those in which the finished parts are removed by compressed air or manually.

The die design should suit the scale of production it will be used for: small-lot, large-lot, or mass production.

Dies should meet the following requirements:

(1) the accuracy and surface finish of stampings should conform to the drawings and specifications;

(2) the working parts of the die must be adequately strong, durable in operation, and easily replaceable when worn out;

(3) the die is to ensure the required hourly output, easy maintenance, safe operation, and reliable fastening in the press;

(4) the die should be designed preferably of standard components, using as few special parts as possible;

(5) the scrap in the stamping operation must be kept at a minimum.

Die components may be divided into the following types:

(a) working components, which participate in the shaping of parts (punches, dies, and their sections);

(b) structural components, which serve for joining the pieces of a die to one another and to the press (upper and lower die shoes, shanks);

(c) guiding components, which ensure accurate alignment of the punch with the die shoe in operation (guide posts and bushings);

(d) feeding components, which feed the stock or blanks to the stamping station;

(e) locating and locking components, which provide for an accurate positioning of the stock or blank in the die and fix it in place while the operation is performed;

(f) stripping components, which are intended for stripping and removing the blanks and scrap after the operation is over (strippers, knockouts);

(g) fastening components, which join and hold together all parts and units of the die (punch holders, die blocks and cases, all fasteners).

Figure 68 is a schematic representation of a press tool comprising all principal components present in any typical press tool.

8.2. Cutting Dies

When blanking non-critical parts of a plain shape under small-lot production, use is sometimes made of blanking and piercing dies without guides; these dies leave open the access to the stamping zone. Such dies are also used for blanking parts right from sheet stock or from sheet trimmings (scrap).

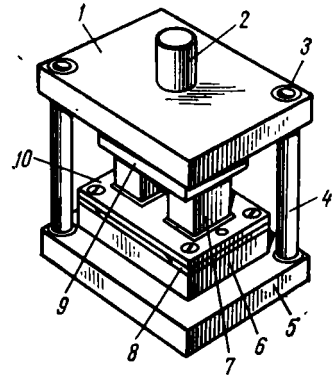


Fig. 68. Press tool components
1—upper shoe; *2*—shank; *3*—guide-post bushing; *4*—guide post; *5*—lower shoe; *6*—die; *7*—punch; *8*—positioners; *9*—punch retainer; *10*—stripper

The dies without guides are simple in design, inexpensive in manufacture, but dangerous in operation, since the operator's hands may be trapped in the working zone of the die. Even special safety guards and precautions do not ensure safety of operation of such dies and do not rule out injuries.

All dies of up-to-date design have guides in the form of heel blocks or posts. In such dies the upper part (punch) is accurately directed and aligned with respect to the die, which improves the accuracy of stampings and ensures a longer life of the tool. The working zone of such dies is, in most cases, closed.

Blanking dies can be either closed or open. In the closed tools, the stripper, which removes the scrap off the punch, is fixed to the die. The stripper has a hole corresponding to the shape of the punch, but made with a lower accuracy than the die clearance. In the open tools, the stripper plate is attached to the top part of the die and, when the slide goes up, some free space is left between the upper and lower parts of the die. The stock fed into these dies is pre-cut from strip or band; bars may also be used.

The dies for cutting off blanks and blanking dies may be made with a stationary (rigid) stop to restrict the feed of stock, or with a movable (spring-loaded) stop automatically actuated by motions of the upper part of the die.

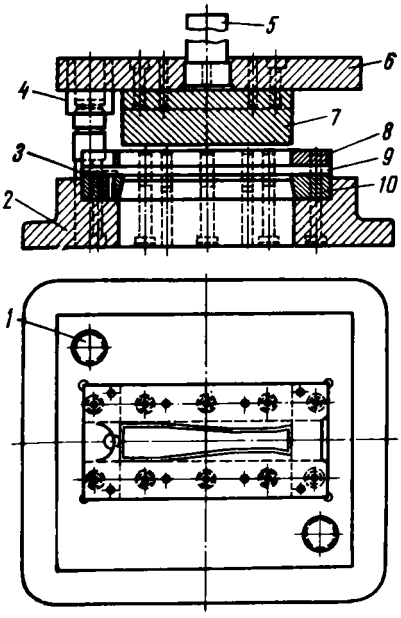


Fig. 69. Closed-type blanking die with guide posts

1—guide post; *2*—lower shoe; *3*—stop; *4*—bushing; *5*—punch shank; *6*—upper shoe; *7*—punch; *8*—stripper; *9*—stock guides; *10*—die

Figure 69 shows a *closed-type blanking die with guide posts.* The press bed accommodates lower shoe *2* with die *10*, while the slide of the press accommodates upper shoe *6* carrying punch *7* whose shank *5* is secured in it.

When the press operates, the punch and slide go up and down. The female die has an opening whose shape and size correspond to those of the part being blanked. The punch is shaped to answer the opening in the die, but is somewhat smaller to provide for the necessary clearance between the punch and die. As the punch travels downwards, it encounters the strip of stock and blanks out a part. The strip of stock is moved over the upper surface of the female die during the period when the punch leaves the die and remains in the uppermost position.

Guide posts *1* press-fitted into lower shoe *2* align the upper and lower parts of the die. Travelling over the posts are bushings *4* press-fitted into upper shoe *6*.

In the process of blanking, the strip of stock is directed by stock guides *9*. When the punch goes up, the strip is removed from it by fixed stripper *8*. Before blanking out the next piece, the strip is fed by the operator to stop *3* (from the right to the left in the Figure).

In the *open-type blanking die* shown in Fig. 70, stripper *3* is secured by screws *4* with springs *6* to the upper shoe

of the die. When punch *5* is in the topmost position, its end is flush with the stripper. As the punch goes down, the stripper presses the strip against die *1*, while the punch blanks out the piece. At this moment springs *6* compress between the upper shoe and the stripper.

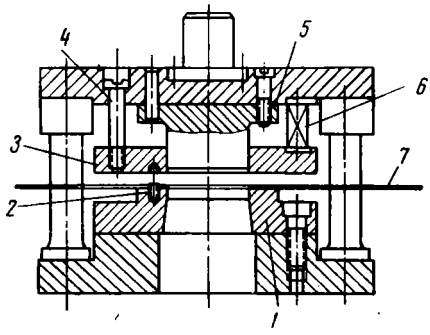


Fig. 70. Open-type blanking die with guide posts

1—die; *2*—stop; *3*—stripper; *4*—screw; *5*—punch; *6*—springs; *7*—strip of stock

Equal spacing between blanked parts in the strip is ensured by stop *2* provided in the die.

In some open-type dies, rubber pads are used in the strippers instead of the steel springs. In either case, when the slide moves up, the punch begins immediately escaping from the die opening, while the stripper is still on the stock holding the latter against the die.

Figure 71 shows a die with a heel block. It is intended for blanking simple-shaped rectangular parts with rounded-off corners. The upper part of the die comprises shank *6*, upper shoe *7*, spacer *8*, and punch retainer *9* with punch *10* upset in it. Components *7*, *8*, and *9* are fastened together by screws and pins.

Lower shoe *14* carries die *13* and heel block *11* which also serves as the stripper. Arranged between the heel block and the die are two guides *12*. To keep the working surface of die *13* and the bottom surface of shoe *14* parallel when the shoe surface is ground, the two components are joined by pins *16* and screws *15* and are not disjoined in die disassembly. Guides *12* overhang from the die and carry tray *1* screwed to them and intended for supporting the strip or band being cut.

When the upper part of the die descends, thrust screw *4* lifts the hook of stop *2* out of the strip. While the part is blanked out, spring *3*, compressed between lever *5* and

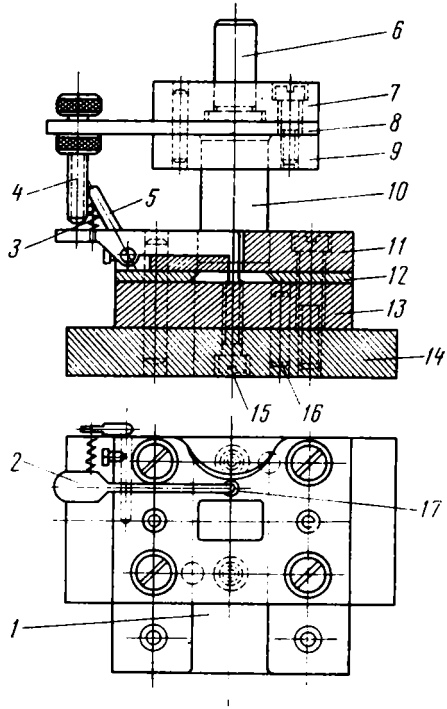


Fig. 71. Die with heel block and automatic stop

1—tray; *2*—stop; *3*—spring; *4*—thrust screw; *5*—lever; *6*—shank; *7*—upper shoe; *8*—spacer; *9*—punch retainer; *10*—punch; *11*—heel block; *12*—guides; *13*—die; *14*—lower shoe; *15*—screws; *16*—pins; *17*—hole

stop *2*, forces the latter to the side opposite to the direction of feed until it bears against the wall of hole *17*. After the punch has moved up, the strip travels forward and the hook falls into the freshly blanked hole whose rear edge rests against the hook, ensuring a feed of just one pitch.

Lately, there appeared a tendency in mechanical engineering to substitute dies with guide posts for those with heel blocks.

Dies for blanking large-size parts are usually made inverted, with the female die arranged on the upper shoe, and

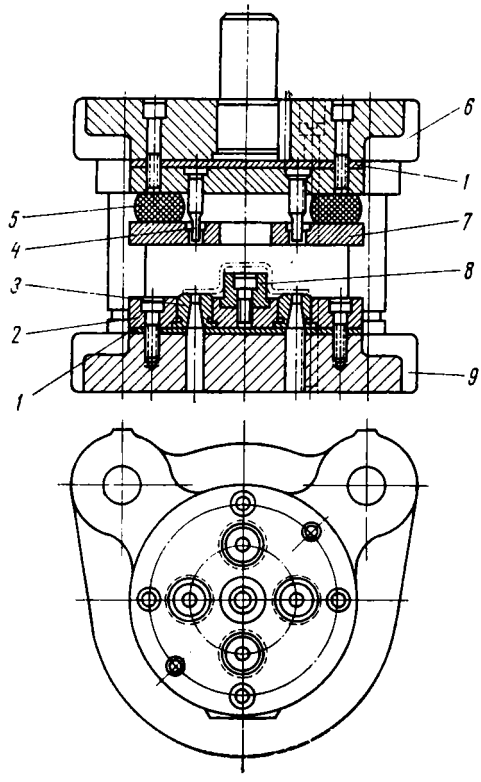


Fig. 72. Piercing die

1—spacer; *2*—die block; *3*—female die; *4*—punch; *5*—rubber pads; *6*—upper shoe; *7*—stripper; *8*—locator; *9*—lower shoe

no guide posts are provided. Such a design obviates the need of a drop-through hole.

Piercing dies are used, as the name implies, for piercing holes in flat blanks and in parts made by bending or drawing.

Depending on the shape of the blank or part to be pierced, the dies can be provided with different blank-holding plates (closed or open) and locking pins to hold the blank firm in place when it is pierced through.

Figure 72 shows the design of a representative piercing die. This is an open-type tool with guide posts and a rubber pad serving as the blankholder. The part is put on locator *8* which holds it in the required position. The pierced parts are stripped from punches *4* by stripper *7* owing to rubber pads *5* which act upon the stripper to press the part against female dies *3* when the punches go down; when the punches ascend, they strip the part off them.

This die is intended for piercing four small-diameter holes. The female dies are made as inserts in die block *2*, thus sparing tool steel and facilitating the manufacture and repair of dies. The figure shows the die in the open position with the punch ends in stripper *7*. For safety reasons, the blank is put on the locator with the aid of tweezers. Punches and female dies for piercing round holes are usually secured in the shoes of the die with their shoulders resting against steel spacers *1* installed below upper shoe *6* and lower shoe *9*.

8.3. Bending Dies

In bending dies the blank should be fixed against shifting in bending. To avoid shifting, the blank is positioned with the aid of holes in it (the holes are sometimes pierced specially for this purpose) or it is held in place by blankholders.

In bending operations most frequently used are dies with guide posts.

Figure 73*a* shows an open V-forming die. The design of this die ensures accurate dimensions of bent ends by placing the blank in locator *6* and onto die *1* to two pins *5*. Before bending, the blank is clamped between punch *4* and special stud *3* actuated by an air-operated cushion of the press through knockout *2*.

A channel-forming bending die is shown in Fig. 73*b*. The blank is placed on blankholder *12* actuated by knockout *2* and positioned to the hole by locator *6* secured on the knockout. When upper shoe *9* and punch *4* go down, the blank is first clamped between the punch and the knockout and then bent to take the shape of the part (a cramp). The bent part is ejected from the die by the knockout actuated by

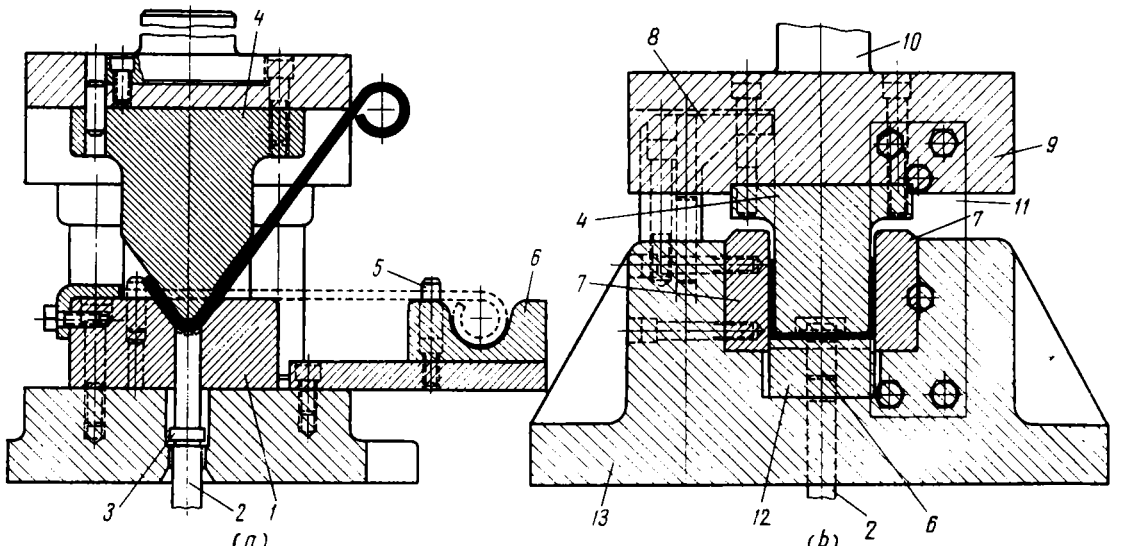


Fig. 73. Bending dies

(*a*) V-forming die; (*b*) channel-forming die; *1*—die; *2*—knockouts; *3*—stud; *4*—punches; *5*—pin; *6*—locators; *7*, *11*—die jaws; *8*—strippers; *9*—upper shoe; *10*—mounting plates; *12*—blankholder; *13*—lower shoe

the lower cushion. If the part is retained on the punch, it is removed by shield-type strippers *8*. Die *1* is made in the form of two jaws *7* and *11* screwed in lower shoe *13*. The die has no guides. Two vertical plates *10* join the upper and lower parts of the die for easier and more convenient mounting of the tool in the press. After the die has been mounted and secured in the press, the plates are removed.

8.4. Drawing Dies

Drawing dies come in two types, depending on the operations performed: dies for the first draw and dies for the second or following draws (redrawing dies).

The dies without blankholders are used for drawing shallow cups, as well as for drawing thick stock when there is no risk of wrinkling.

Spring or rubber-pad blankholders are arranged in the upper part of drawing dies. They are used in shallow drawing. Dies for large and deep draws, requiring considerable pressure, are provided with a cushion built in below the lower shoe and the bolster plate. All up-to-date presses are provided with air-actuated cushions.

Drawing tools without blankholders are simple in design (Fig. 74*a*); they comprise die *4* attached to the bottom of the die and punch *3* with rounded-off working edges at the bottom and shank *1* at the top for securing the punch in the press slide. For the sake of tool steel saving, die *4* is made only as thick as its working portion and placed on case *5* mounted on lower shoe *6*. The lower shoe has an opening accommodating rod *8* of knockout *7*. Guide plate *2* is intended to align and direct the punch.

Figure 74*b* presents a tool with a blankholder intended for the first drawing operation. The blankholder is actuated by an air pad. Draw punch *3* is arranged in the lower part of the tool lower shoe *6*, while draw die *4* is secured on upper shoe *11* together with knockout *7* actuated from springs *13*. The pressure against annular blankholder *10* is transferred from pneumatic pad *9* through rods *15*. The air pressure in the pad is 4-5 atmospheres. When press slide *12* descends, the die face presses blank *14* against blankholder *10* and goes on travelling together with it, which makes

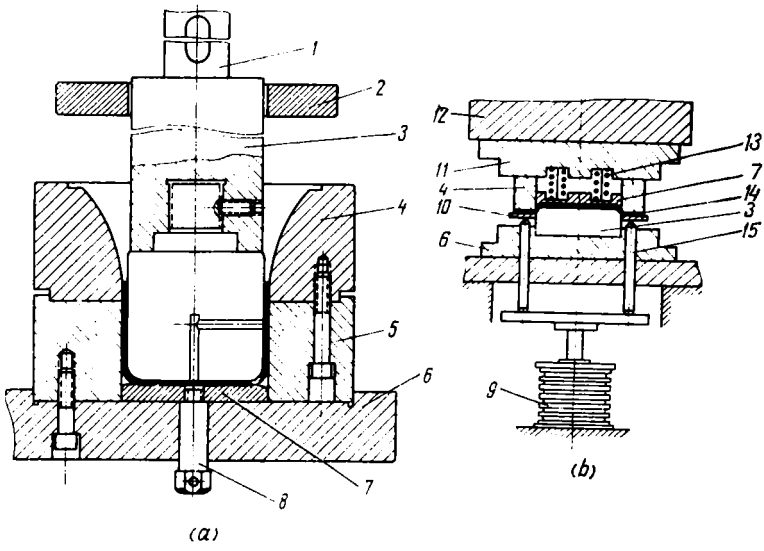


Fig. 74. Drawing dies

(*a*) tool without blankholder; (*b*) tool with blankholder; *1*—shank; *2*—guide plate; *3*—punch; *4*—die; *5*—case; *6*—lower shoe; *7*—knockouts; *8*—rod; *9*—pneumatic pad; *10*—blankholder; *11*—upper shoe; *12*—slide; *13*—spring; *14*—blank; *15*—rods

the blank gradually slip off from under the blankholder and to form an envelope around the punch, acquiring the required shape.

Redrawing dies, like the dies for the first draw, may be with or without a blankholder.

Redrawing dies without blankholders are used only on single-action presses for a moderate decrease in the previously drawn diameter and for drawing parts of a considerable thickness. The redrawing dies are similar in design to dies for the first operation, the basic difference being that the shape and the size of the locator correspond to those of the cup made in the first operation.

Figure 75*a* shows a redrawing die without a blankholder.

In multistage drawing of deep parts without a blankholder, cracks may occur at the top of the cap. This may be prevented by making use of such a die as that shown in Fig. 75*b*.

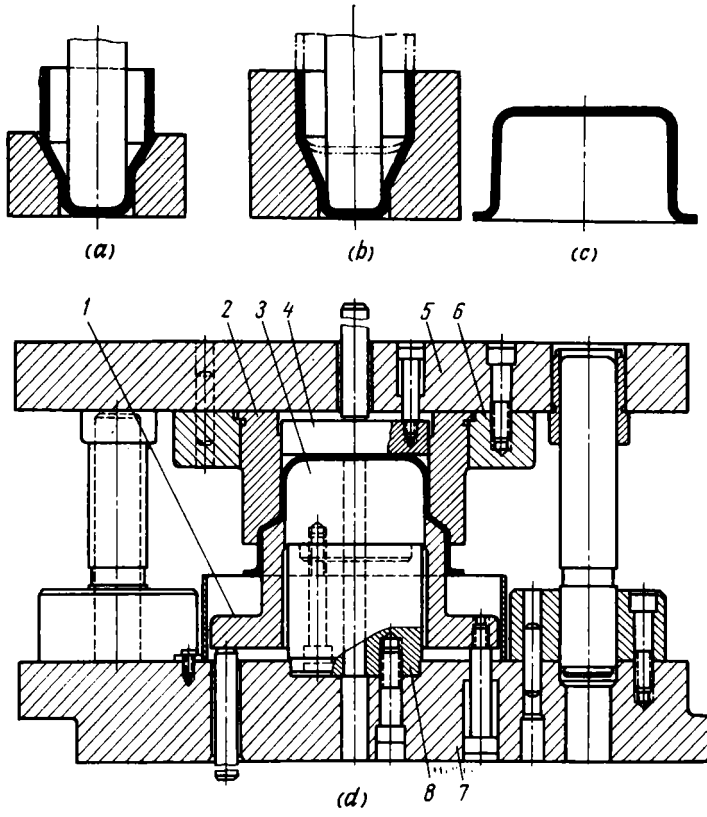


Fig. 75. Redrawing dies

(*a*) redrawing female die; (*b*) elongated female die for redrawing deep cylinder without a blankholder; (*c*) blank after first draw; (*d*) redrawing die with a blankholder; *1*—annular blankholder; *2*—die; *3*—punch; *4*—knockout; *5*—upper shoe; *6*—case; *7*—lower shoe; *8*—punch retainer

When making a cylindrical cup in the redrawing die shown in Fig. 75*d*, the blank obtained in the first drawing (Fig. 75*c*) is placed on annular blankholder *1*. In the downstroke of the slide, die *2* clamps the blank, then punch *3* penetrates in the blank and draws it until the blank bottom rests against knockout plate *4* which, at that moment, contacts

upper shoe *5*. Die *2* is held in place by case *6*, while the punch is connected with lower shoe *7* through punch retainer *8*.

8.5. Forming Dies

Forming dies are much like bending dies with blankholders. They are normally provided with guide posts.

Wide application has been found by dies for beading and flanging operations. Figure 76*a* shows a die for flanging the edge of a shaped disc. The workpiece that has been blanked out along the contour, drawn, and pierced, is placed in the lower part of the die. As the press slide descends, stripper *1* actuated by springs *2* holds the blank against plate *3*. In further downward movement of the slide, die *4* presses against the blank edge with its rounded-off recess, thus performing the flanging operation. With the upward stroke of the slide, plate *3* actuated by spring *5* ejects the ready article from the lower part of the tool and stripper *1* throws it off the upper die part. The quality of flanging depends on the smoothness of the rounded-off recess in the upper die.

Figure 76*b* shows a press tool for beading the edge of a conical cup. In such a die the blank is held up by a rubber cushion and the pressure is applied to the flange rib.

Shown in Fig. 76*c* is a die for shaping a pipe tip. For removing the formed article, die *6* is made split. Punch *7* descends and forces some of the pipe material to set down and flow into the annular groove of the die.

8.6. Combination and Progressive Dies

A *combination die* for piercing a hole and blanking a part in a single operation is shown in Fig. 77. This tool serves for making a blank for an octahedral nut. The strip stock is fed into the tool to stops *1* and *2*. When the press slide descends, piercing punch *9* enters into blanking punch *14* and pierces a hole, whereas blanking die *7* embracing blanking punch *14* blanks the nut out over the external contour. With the reverse stroke of the slide, stock stripper *12*, driven through rods *15* from the air-operated cushion of the press, removes the strip of stock from blanking punch *14*,

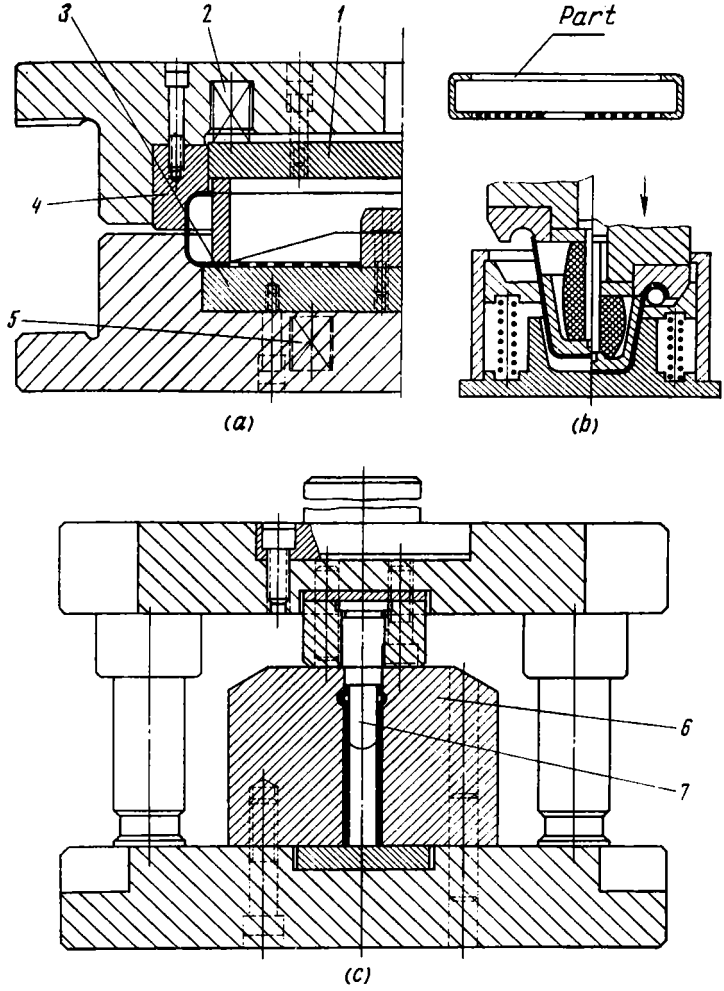


Fig. 76. Flanging and beading dies

(*a*) for inward flanging of shaped-disc edge; (*b*) outward beading of conical-cup edge; (*c*) shaping of pipe tip; *1*—stripper; *2*, *5*—springs; *3*—plate; *4*, *6*—female dies; *7*—punch

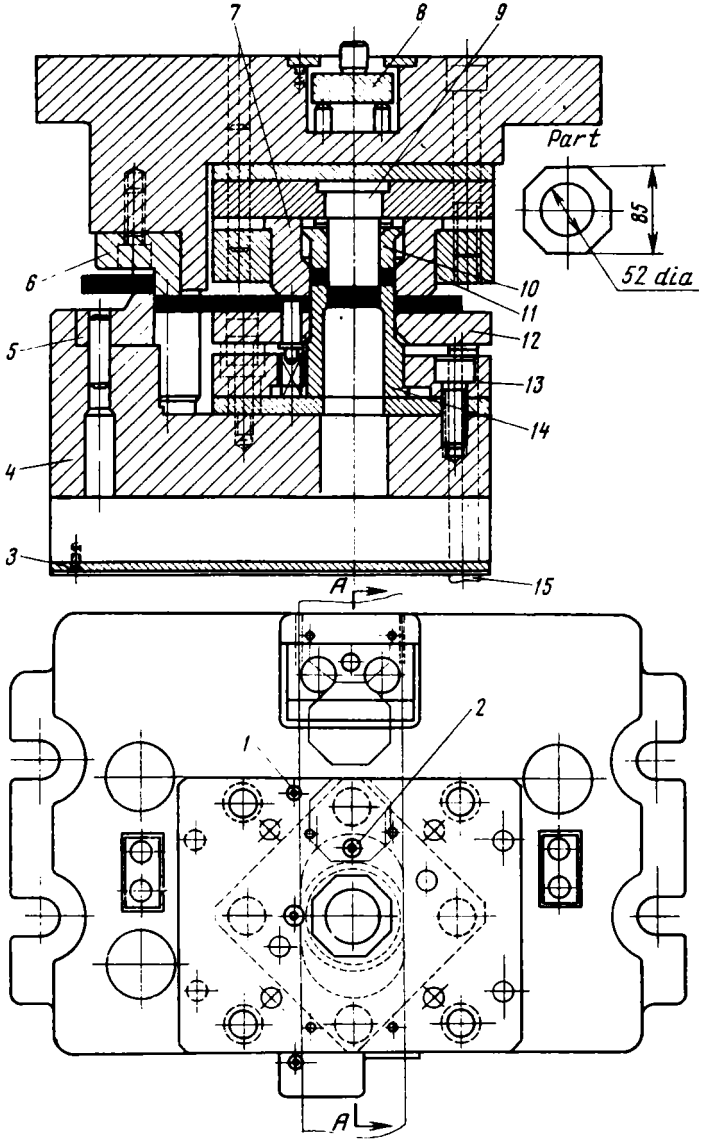


Fig. 77. Combination blanking-and-piercing die for thick sheets

1, *2*—stops; *3*—membrane; *4*—lower shoe; *5*, *6*—blades; *7*—blanking die; *8*—knockout; *9*—piercing punch; *10*—part stripper; *11*, *13*—retainers; *12*—stock stripper; *14*—blanking punch; *15*—rod

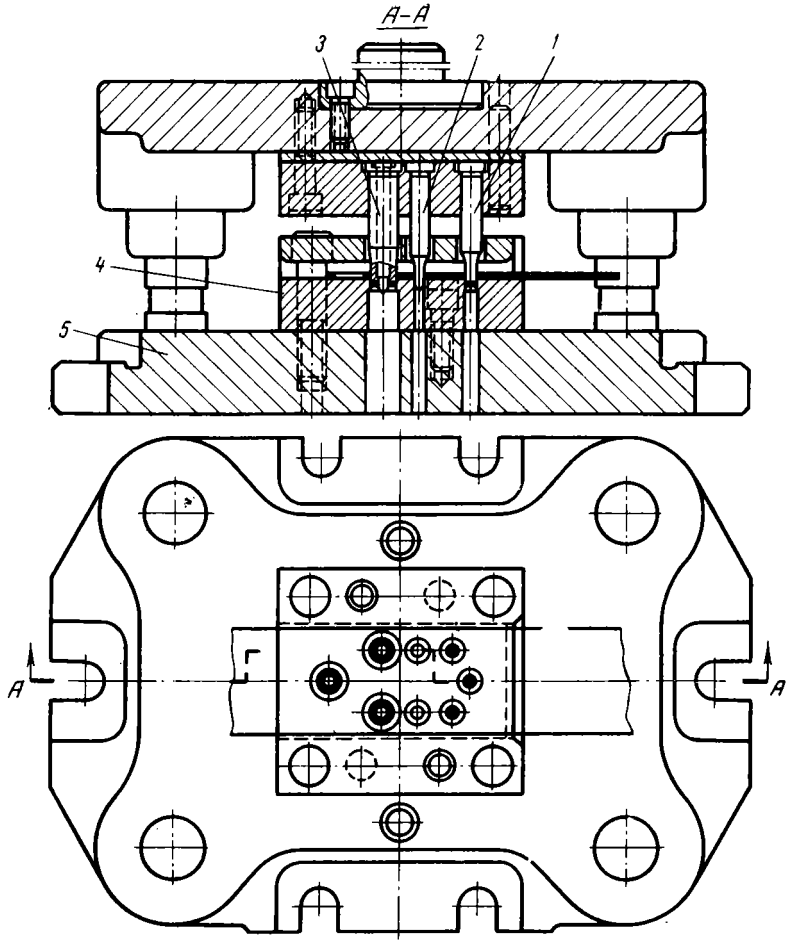


Fig. 78. Three-station progressive die for making washers
1, *3*—punches; *2*—pilots; *4*—die; *5*—lower shoe

while part stripper *10* actuated by the press yoke through knockout *8* ejects the ready article from blanking die *7* at the end of the slide stroke. Blanking punch *14* and die *7* are set in the sockets of retainers *13* and *11*, respectively, which makes the manufacture and repair of the tool more simple and less expensive.

The slug produced in piercing the hole in the nut falls down through the hole in lower shoe *4* onto membrane *3* wherefrom it is periodically removed. For easier removal of strip wastes, the rear of the tool is provided with blades *5* and *6* which cut the strip into pieces.

Figure *78* shows the design of a *progressive die* for making washers. The die produces three washers in a stroke. It is intended for piercing and blanking strip on a press provided with double roller feeder. In the first position, punches *1* pierce three holes. Then the strip is fed by one pitch and in the second position pilots *2* locate the strip, ensuring accurate feed. In the third position, punches *3* blank the washers which drop through the holes in die *4*, lower shoe *5*, and the bolster plate.

8.7. Die Components

In spite of the great variety of dies, most of them have certain components similar in purpose and design. To facilitate design, manufacture, maintenance, and repair of dies, similar units and components have been standardized.

Standardization reduces the stock of rapidly wearing components, contributes to wider interchangeability, decreases the required number of dies, improves their reliability, cuts down the cost and time of die manufacture and repair.

After a complex of engineering standards for dies had been introduced, the nomenclature of die components became appreciably narrower, and dies incorporating up to 80 per cent of standardized components are known today.

Described below are units and components most widely used in pressworking dies.

Die sets consist of an upper shoe, a lower shoe, and guide posts or straps.

In most cases the sets have two guide posts positioned diagonally, in the rear, or axially (Fig. 79). For large,

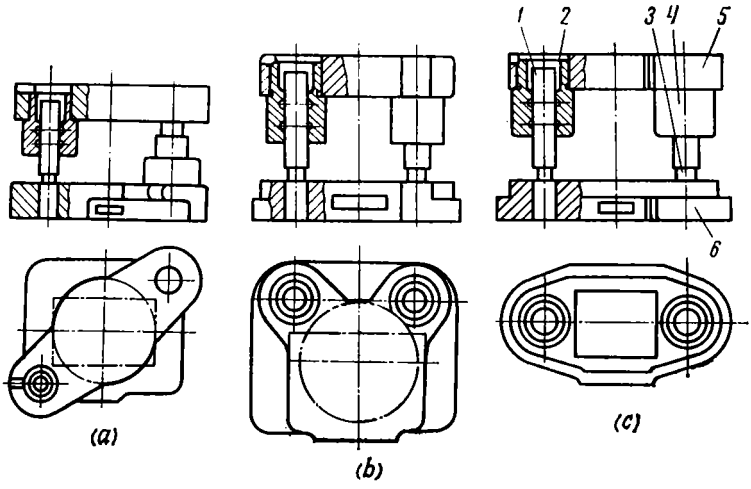


Fig. 79. Commercial die sets

(*a*) diagonal posts; (*b*) rear posts; (c) axial posts; *1*, *3*—guide posts; *2*, *4*—guide-post bushings; *5*—upper shoe; *6*—lower shoe

very complicated, or highly accurate stampings the die sets are made with four posts.

In some sets one of the posts is press-fitted into the lower shoe and the other into the upper shoe, which allows regrinding the die without disassembly.

The lower and upper shoes are iron or steel castings. Guide posts and bushings are made from low-carbon steel, carburized and hardened.

Die sets for cutting dies with ball-bearing guide posts are commercially available for use in high-speed presses employed in large-lot and mass production. As compared to the slide-type guides, the ball-bearing guides ensure easier movement, do not heat in high-speed work, wear down very slowly, and are very accurate in operation. The ball-bearing guides do not need any lubrication for several months of operation after they are lubricated during the set assembly.

To enjoy an accurate performance of the die irrespective of the condition of the press slide guides, die sets with

ball-bearing guides are provided with shanks having "float-type" attachment to the upper die shoe.

The industry also produces die sets completed with rectangular or round steel plates intended to retain a punch, a female die, a stripper, and other components. A die set of this type, selected to suit the size of the stamping, allows construction of any die by supplying the standardized set with a punch, a female die, and a stripper of the required shape.

The completed die sets for cutting tools (blanking, piercing, progressive and similar tools) are made with fixed strippers (Fig. 80*a*) and with top blankholders (Fig. 80*b*).

Guide posts and bushings ensure accurate alignment of the upper shoe with respect to the lower shoe and facilitate tryout of the tool in a press.

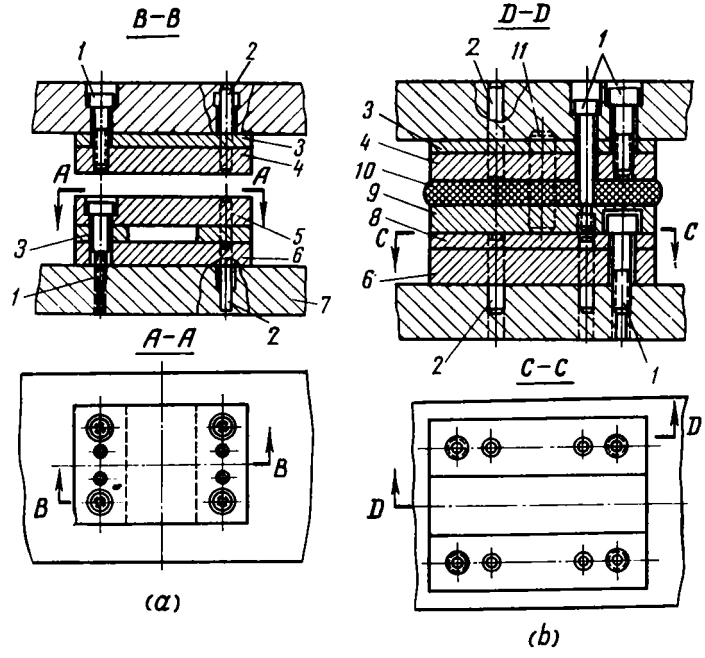


Fig. 80. Completed die sets

(*a*) set for cutting die with fixed stripper; (*b*) set for cutting die with top blank holder; *1*—screws; *2*—pins; *3*—spacer plates; *4*—punch retainer; *5*—stripper *6*—die; *7*—lower shoe; *8*—strip guide; *9*—blankholder and stripper; *10*—spacer *11*—guide

The guide posts are so arranged in the die as not to interfere with positioning the blanks or removing the finished articles and not to cause any hazard to the operator's hands. The height of the bushings (Fig. 81*a*) is selected so as not to allow their escape from the post when the slide is in its uppermost position.

A common practice is to use plain cylindrical bushings with the press-fitting and guiding sections of the same diameter (Fig. 81*b*).

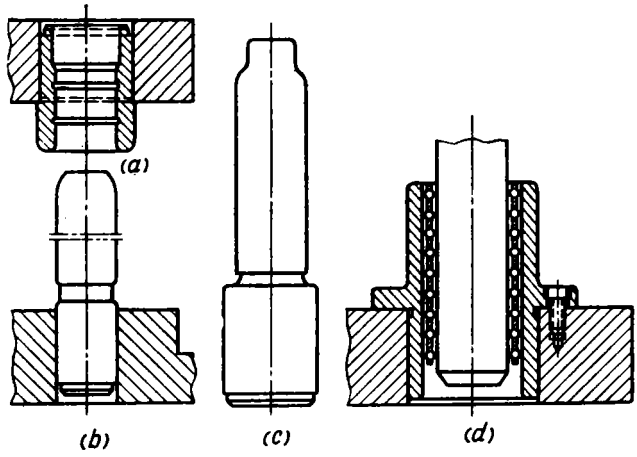


Fig. 81. Guide posts and bushings
(*a*) bushing; (*b*) plain post; (*c*) shoulder post; (*d*) ball-bearing guide

In large tools or when it is easier to drill holes for guide posts and bushings in the upper and lower shoes with one setup, use is made of shoulder posts (Fig. 81*c*). In this case the diameter of the post section press-fitted into the die provides for a more accurate alignment of the upper part with the lower part and reduces the time needed to drill holes for the guides.

Dies for making high-precision parts, dies employed on high-speed presses, dies with cemented-carbide tips, and shaving dies make use of ball-bearing guides (Fig. 81*d*)

which contribute to smooth strokes and no-clearance guiding. The ball-bearing guides can be mounted either in the upper or in the lower shoe of the die. Usually, they are arranged in pairs, one guide in the upper shoe, the other in the lower shoe, in order to make possible grinding of the die and punch working faces without disassembling the tool.

Shanks. All types of ordinary tools intended for cutting operations use standard shouldered shanks (Fig. 82*a*). Such a shank is press-fitted into a specially bored hole of the upper shoe. In cases where accurate alignment of the tool is of special importance, the shank forced in the shoe is given additional polishing after assembly.

Threaded shanks (Fig. 82*b*) are used in drawing and bending tools with guide posts; in large-size tools the shanks are threaded and shouldered (Fig. 82*c*).

In large-size dies with guide posts, where the shank serves for centring, or in dies whose design allows no other shanks, use is made of shanks of the type shown in Fig. 82*d*.

A shank for screwing the punch of a drawing die (the punch installed directly into the shank) is shown in Fig. 82*e*.

When blanking out small-size accurate parts from thin sheets and when using tools with cemented-carbide punches and dies or with ball-bearing guides, use is made of self-aligning ("floating") shanks and spherical inserts (Fig. 82*f*).

For heavy-duty work in bending tools, fork-type shanks of the design shown in Fig. 82*g* are applied.

If the tool shank does not fit in the press slide hole, adapter shanks (Fig. 82*h*) or split adapter bushings (Fig. 82*i*) may be resorted to.

Punches. Pressworking tools employ different types of punches.

Punches may be classified into round and shaped, integral and sectional, undetachable and quick-change types.

Integral punches are press-fitted into the upper shoe with subsequent upsetting of their idle faces or a shoulder is made on the face. Both the upsetting and the shoulder serve for securing the punch in the shoe when the press slide ascends.

Quick-change punches with a cylindrical idle part are fixed with a ball which catches a recess in the punch. Such

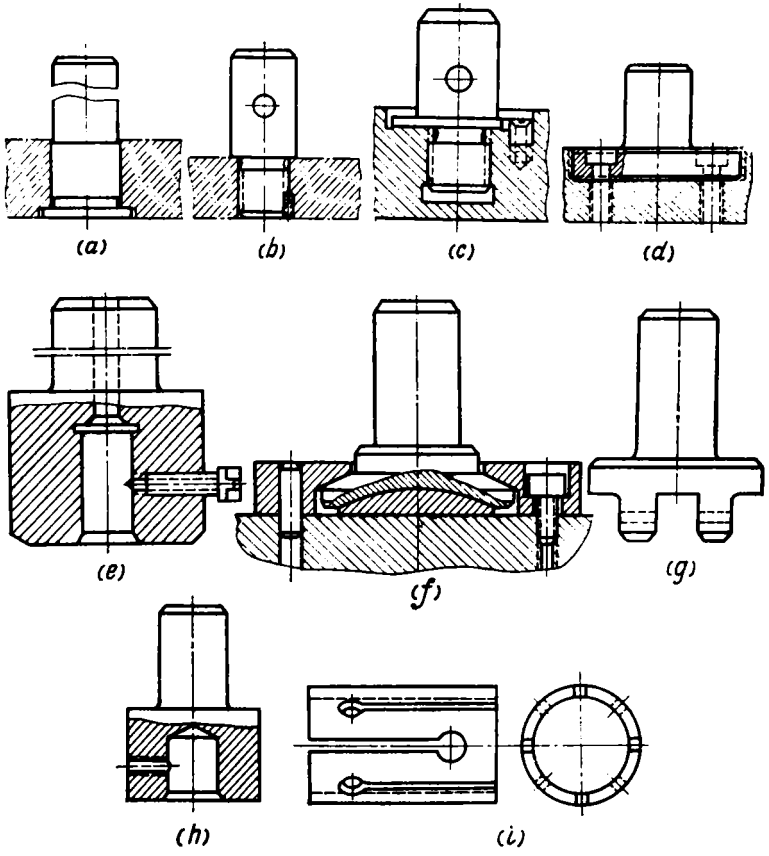


Fig. 82. Die shanks

(*a*) shouldered; (*b*) threaded; (*c*) shouldered and threaded; (*d*) fastened with screws; (*e*) for screw fastening of punch; (*f*) self-aligning (floating); (g) fork-type; (*h*) adapter; (*i*) adapter bushing

punches can be replaced without removing the tool from the press.

Shaped punches are fixed in place by upsetting their non-working part or by means of screws and pins. Figure 83 shows basic types of round and shaped punches.

Round punches (Fig. 83*a*), fixed by upset head, are used for piercing holes up to 12 millimetres in diameter, especially when several piercing punches must be spaced close together and no shoulder can be made for fixing the punch.

The punch secured by a flange (Fig. 83*b*) is intended for piercing holes. The long straight portion *k* of such punches is introduced into the hole of the pilot plate of the tool.

The shouldered punch with a flange (Fig. 83*c*) is intended for piercing large holes and blanking. If a punch is over 45 millimetres in diameter, its face is recessed to reduce the surface to be ground in resharpening.

Figure 83*d* shows a quick-change punch fixed by a spring-loaded ball lock. The punch is used for piercing numerous holes in stock not thicker than 3 millimetres. To replace the punch, the ball must be pressed upon through hole *m*. A similar design (Fig. 83*e*) is suitable for heavy-duty piercing

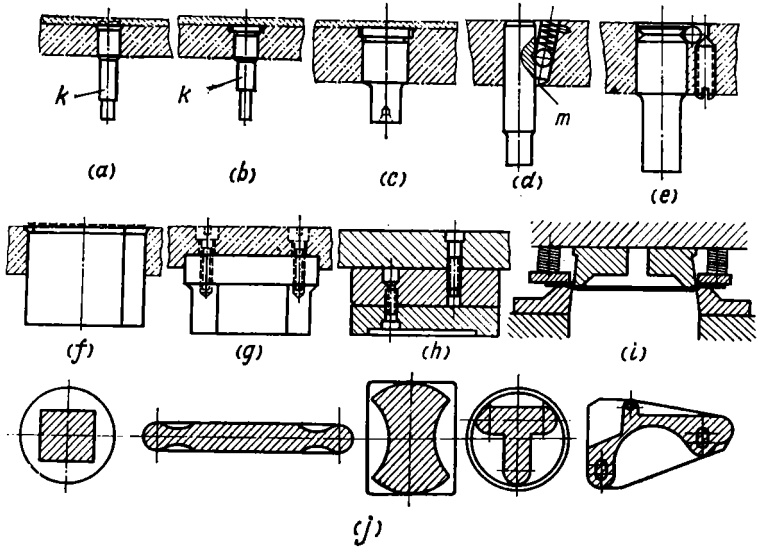


Fig. 83. Piercing and blanking punches and methods of their attachment in die upper shoe

operations and for large-size tools. The ball is secured in place by means of a thrust screw.

Shaped punches may be classified into four basic types. The upset-end punch (Fig. 83*f*) is used for blanking parts of small and moderate size. For blanking intricately-shaped parts of moderate size, flanged punches (Fig. 83*g*) are made, the flange serving to attach them to the die upper shoe by screws and pins.

The punch shown in Fig. 83*h* comprises two parts: a working portion and an extension. This design saves tool steel in blanking large parts of a simple shape.

The split-design punch (Fig. 83*i*) is used for blanking very large intricately-shaped parts. It consists of separate cutting sections fitted to one another and mounted on the upper shoe. The sections are secured by screws and pins.

Punches with an intricately-shaped working portion (Fig. 83*j*) are provided with a bearing footing of a simple configuration, whose maximum dimensions must coincide with the overall dimensions of the punch working outline.

Female dies may be classified into integral and sectional; round, rectangular, and shaped; undetachable and quick-change.

Undetachable dies are press-fitted or bolted to the die shoe. Quick-change dies are secured by screws or by a ball lock.

The blanking and piercing dies have one feature in common, which is the shape of their working portion. Figure 84 presents basic types of dies.

Round blanking dies (Fig. 84*a*) are used for obtaining round blanks.

For simple progressive and combined blanking and piercing operations on moderate-size parts wide use is made of the type of dies shown in Fig. 84*b*.

When blanking intricately-shaped parts, large parts, or narrow parts with acute angles, split dies are used (Fig. 84*c*). The split design of the dies makes their manufacture and finishing easier and precludes warping in hardening.

Split dies shown in Fig. 84*d* are applied for blanking large-size intricately-shaped parts. Such dies consist of separate sections fitted to one another and mounted on the die

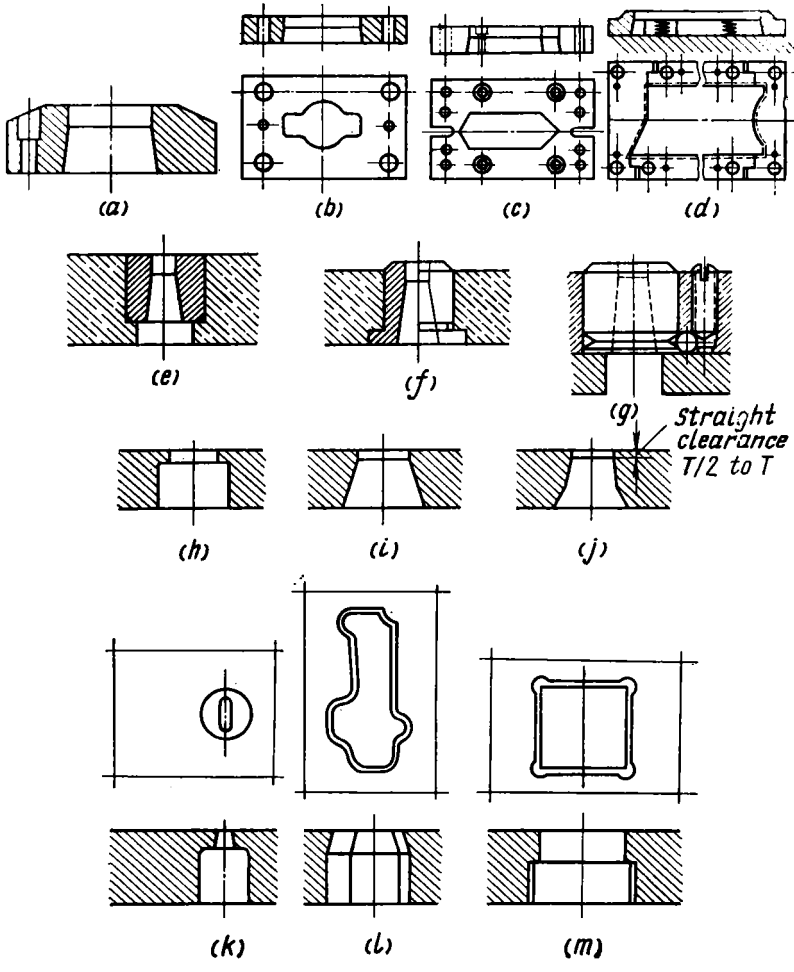


Fig. 84. Blanking and piercing female dies

lower shoe. Blanking with such dies involves reverse knocking-out of the blanked part.

Piercing dies used in multipunch (perforating) press tools are generally made as replaceable cylindrical buttons. Plain (Fig. 84*e*) and flanged (Fig. 84*f*) buttons are press-fitted into the die shoe. They are used only for piercing round holes.

Quick-change cylindrical buttons secured by a ball lock with a thrust screw (Fig. 84*g*) are used for making holes up to 30 millimetres in diameter.

The shape of the die hole is selected to suit the stock thickness. When piercing a few closely spaced holes of up to 8 millimetres in diameter, the dies of the type shown in Fig. 84*h* are used. The same holes are also made for blanking parts of a simple outline (Fig. 84*k*). In dies with an irregular shape, holes are made as shown in Fig. 84(*i* and *l*). The shape with a larger height of the working taper or tapered over the entire height (Fig. 84*j*) is used for dies of long service life for work on small workpieces. Dies with backward ejection of workpieces (mainly in combined tools) use the shape shown in Fig. 84*m*.

Strippers. Depending on the die design, punch size, and stock thickness, strippers can perform removal of parts, removal of scrap from the punch, and accurate guiding of the punch.

The punch is to be accurately guided by the stripper in order to provide a uniform die-to-punch clearance on all sides. The clearance between the punch and stripper is commonly equal to 0.8 that between the punch and die and should never exceed the latter clearance.

Strippers can be of fixed or pressure type.

Fixed strippers are used in blanking dies which cut pieces out of a strip and drop them through the die opening, as well as in piercing tools where the blank need not be held against the die (provided the stripper presents no obstacle for placing the blank in, and removing the part from, the tool). For guiding the punch, only fixed strippers are used. The punch should be guided by the stripper in tools that have no guide posts, as well as in multipunch tools with punches of different sizes, in tools having slim punches and in those employing top blankholders.

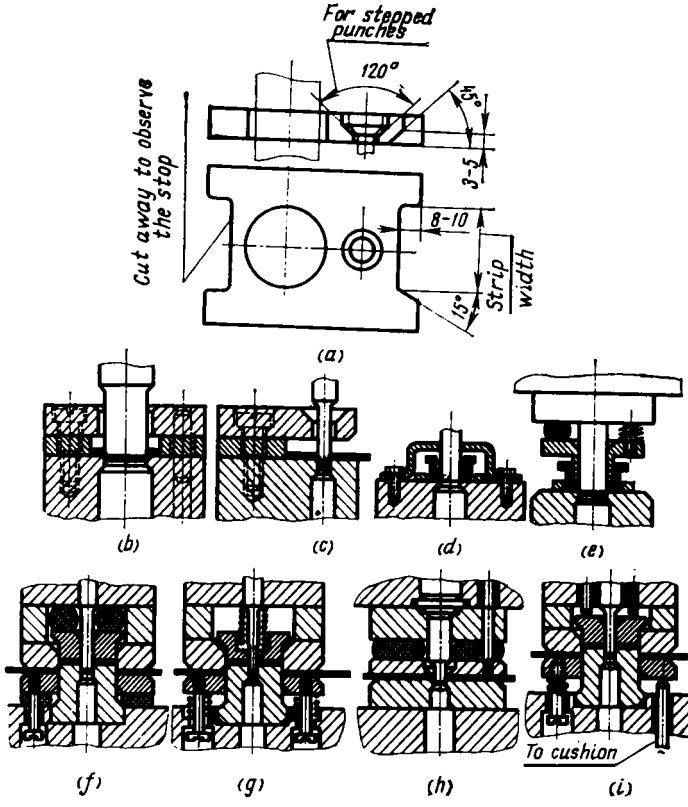


Fig. 85. Strippers

(*a*) fixed stripper; (*b*) closed fixed stripper; (*c*) open fixed stripper; (*d*) cramp-shaped fixed stripper; (*e*) cramp-shaped pressure-type stripper; (*f*) rubber-fitted pressure-type stripper; (*g*) spring-actuated pressure-type stripper; (*h*) stepped pressure-type stripper; (*i*) cushion-actuated pressure-type stripper

For strip introduction into the die and letting it out therefrom, strippers are provided with cutouts as shown in Fig. 85*a*. Figure 85 (*b*, *c*, and *d*) represents different design versions of fixed strippers.

Pressure-type strippers are characterized by that the movement and the blankholding force are due to springs,

rubber pads, or pneumatic and mechanical devices incorporated in press tools and presses. Pressure-type strippers find application in combination dies and in dies with top blankholders. The stripper shown in Fig. 85*e* serves also as the blankholder and as the locator of the inside contour of the part. The diagrams in Fig. 85 (*f*, *g*, *h*, and *i*) present different design versions of pressure strippers.

Guides direct the strip motion. When the strip is to be pressed against one side of the guide, provision is made of side pushers.

Of much importance are the clearances between the strip and the walls of the guide, since they determine the accuracy of stock guiding in the die. The clearance depends on the width and thickness of the strip and may be from 0.5 millimetre (stock width up to 50 millimetres, thickness up to 1 millimetre) to 2.5 millimetres (stock width over 200 millimetres, thickness over 5 millimetres).

For dies with trimming punches the distance between the plates is chosen with due account to the stock width cut away by the punches. The distance between the guide plates at the die outlet is equal to the distance between the trimming punches.

Figure 86 presents the design of guides. For thin stock, long guides are used with special devices capable of holding the strip as it moves in the guide.

Stops are intended for limiting the feed of strip into the tool. Figure 87 shows the basic types of stops. The pin stop of Fig. 87*a* is used in tools with fixed strippers where stock is fed by hand; the hooked pin shown in Fig. 87*b* is similar to it in purpose, but used when the locating portion of the stop must be arranged at a distance from the cutting edge of the die.

Combination dies make use of sinking stops supported with a spring (Fig. 87, *c*, *d* and *e*) or with a rubber pad (Fig. 87*f*).

When blanking parts 6 to 20 millimetres wide by 0.8 millimetre thick or thicker in tools with a fixed stripper use is made of spring-returned reversing stops (Fig. 87*g*).

When the strip is set in progressive tools for the first stroke, provision is made of side pushers with or without a spring (Fig. 87*h*).

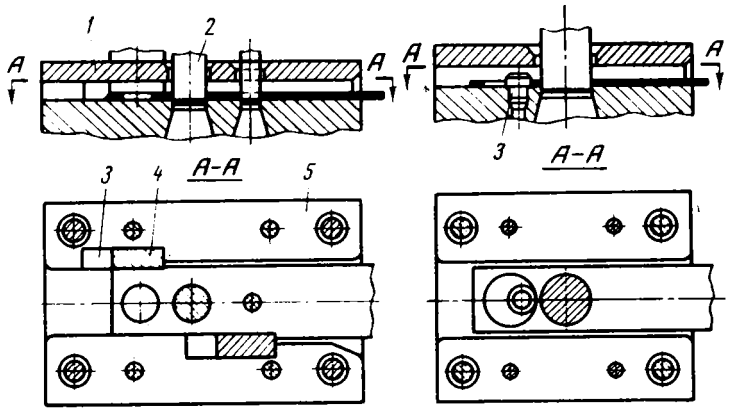


Fig. 86. Guides in progressive dies
1—stripper; *2*—punch; *3*—stop; *4*—trimming punch; *5*—guide

Blanking and progressive tools for small and medium-size parts of stock thicker than 0.5 millimetre are provided with latch stops (Fig. 87*i*), connected with the upper shoe of the die and actuated by the downward stroke of the press slide.

Pilots. In progressive tools, the final position of the strip (with the first hole pierced) is fixed by pilots which correct errors of feeding and provide for accurate location of pierced hole.

In multirow piercing, two pilots are used. The head of a pilot must be pointed and have a tapered, square, or irregular shape to suit the hole pierced in the part. Figure 88*a* shows a few types of round pilots.

Locators. To lock pre-cut blanks, use is made of different locators whose design depends on the shape of the blank. The blank can be located over the external contour or along the contour of a hole in it. Figure 88(*b*, *c*, *d*, and *e*) shows locators of the most widely used types

As has been mentioned above, in some cases blanks may be located by means of holes specially pierced for this purpose.

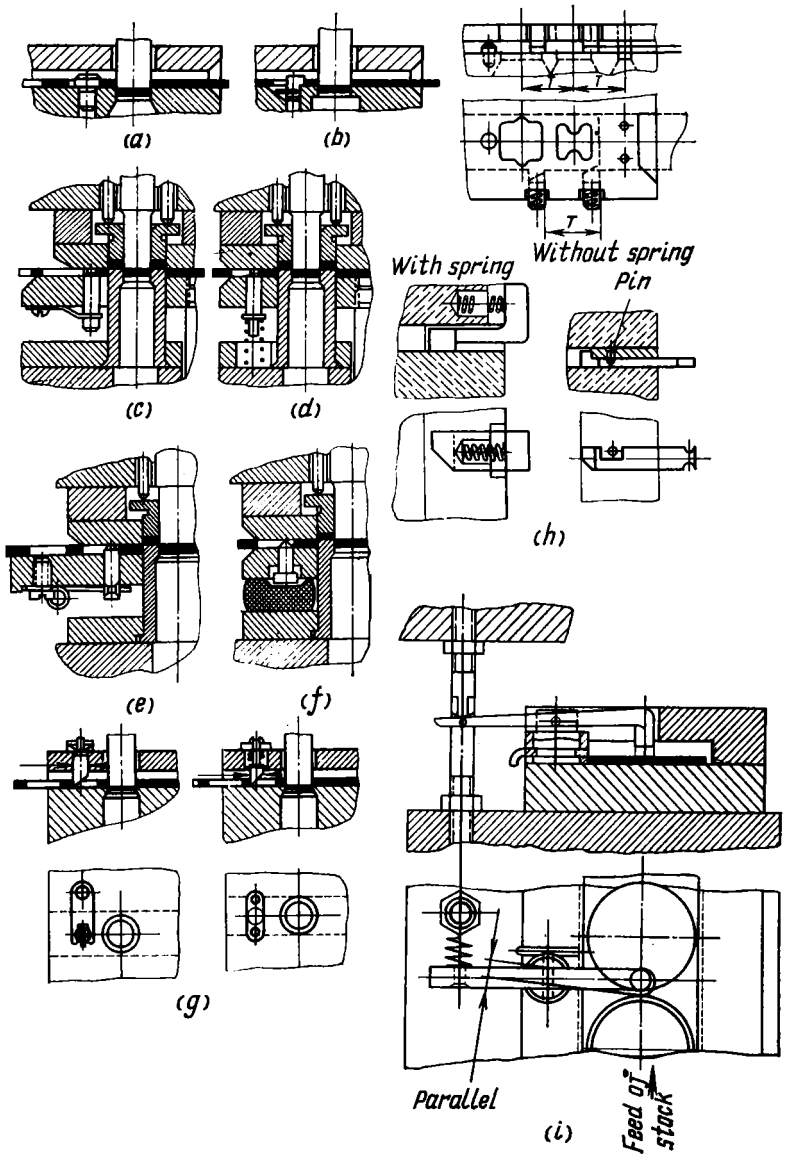

(a)
(b)
T
T
(c)
(d)
With spring
Without spring
Pin
(h)
(e)
(f)
(g)
Parallel
Feed of stock
(i)

Fig. 87. Stops

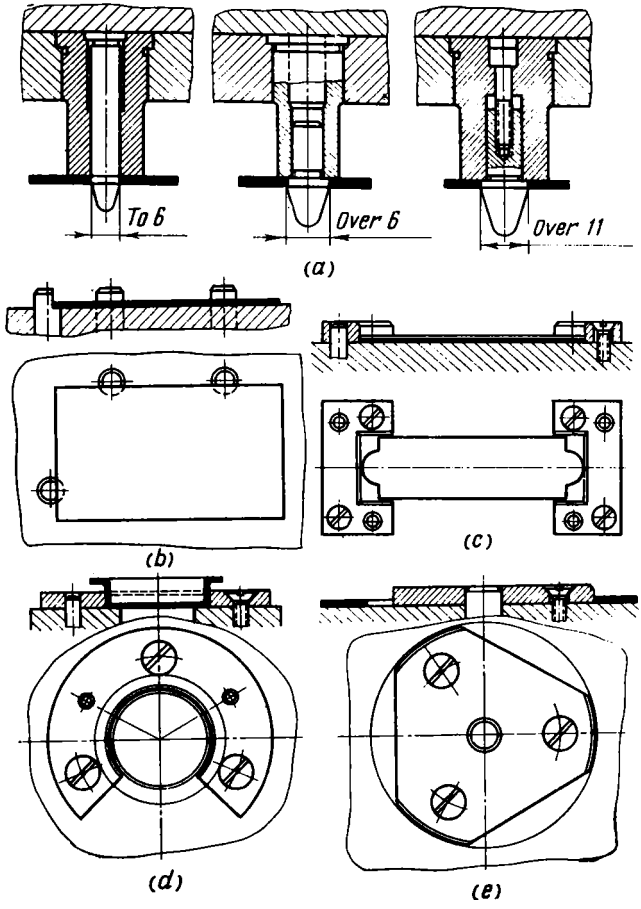


Fig. 88. Pilots and locators
(*a*) round pilots for holes of different diameters; (*b*) pin-type locators; (*c*), (*d*), (*e*) plane-type locators

Cams. Combination dies are sometimes provided with cam-operated punches for piercing side walls of hollow or bent parts. They allow piercing one or more holes and combining the piercing with other operations. Cams are also used for bending the flanges in stampings. Some types of cams are shown in Fig. 89.

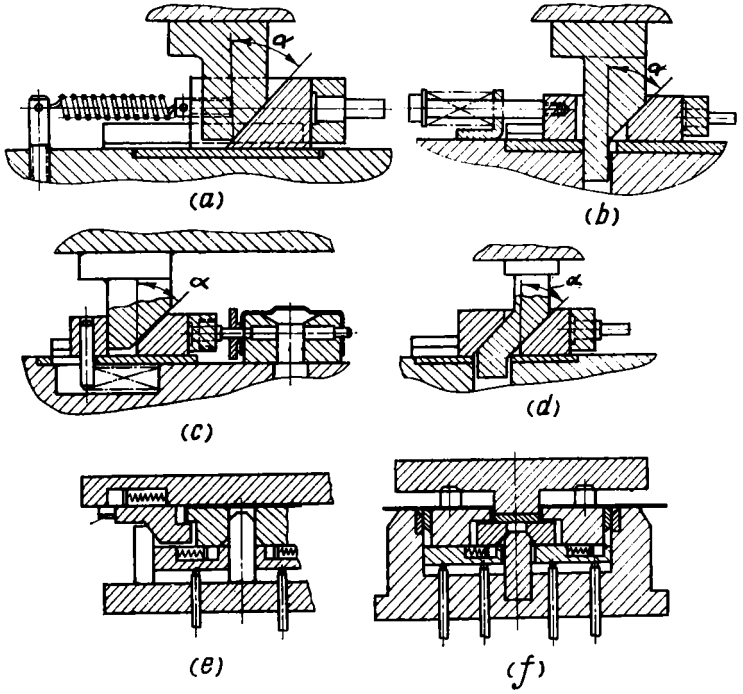


Fig. 89. Cams for dies
(*a*), (*b*), (*c*), (*d*) piercing side holes in hollow parts; (*e*), (*f*) flanging; α—cam angle

8.8. Sintered-Carbide Dies

A longer life of tools for different pressworking and upsetting operations can be achieved by using inserts made from tungsten and cobalt carbides.

Carbide tools have found widest application in large-lot and mass production, where conventional steel dies and punches do not prove stable enough, which calls for frequent duplication of dies. The life of carbide blanking dies rises by 8 and more times. This effect grows manifold when operating on high-strength sheets of stainless, electrical, and similar steels: carbide dies in such cases are 50 times as durable as conventional dies.

Carbide dies differ somewhat in design from steel dies, which is due to the physical and mechanical properties of carbides. The design and manufacture of such dies must ensure:

high stiffness of the die structure;

high wear resistance of guide posts, bushings, stock guides, stops, and other die components;

secure fastening of carbide inserts and their accurate fitting to the bearing surfaces;

minimum penetration of the punch into the die, ensured by application of limiting rests;

elimination of the effects of inaccurate travel of press slide by using float-type shanks and symmetrical arrangement of guide posts with respect to the contour of the cut;

increased punch-to-die clearance.

Figure 90 describes the design of a draw press tool with a sintered-carbide die (*T*) press-fitted into the case. The case-and-die assembly is mounted in a holder (Class 2 accuracy, tight fit). As is seen from the figure, the tool has a float-type shank and ball-bearing guides.

Carbide parts can be press-fitted into the punch and die bases, or brazed to them, or else fastened by wedges and screws. The mechanical fastening is most reliable and provides for the longest life of press tools.

The diagram of Fig. 90*a* shows the die fastening by a wedge. The attachment will be reliable if the wedge is precisely fitted over the die relief and the case side. It is also necessary to fit the bearing surface of the case, spacer, and die to the bottom of the case socket. Fig. 90*b* shows the attachment of a round die secured in the case by light-drive fit of Class 2 accuracy. The die has a shoulder which rests against a spacer and the shoe.

The die may be fitted with interference by a tapered mating as shown in Fig. 90*c*. This method is especially convenient when several die inserts are press-fitted into one die retainer.

Figure 90(*d*, *e*, and *f*) shows methods used most frequently for securing sintered-carbide punches using dowel pins and screws.

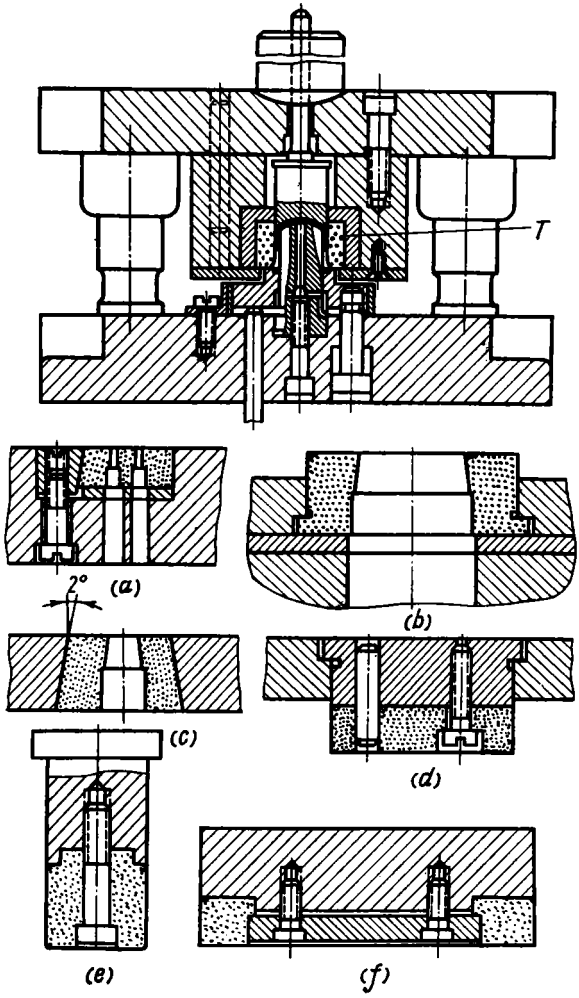


Fig. 90. Draw press tool with sintered-carbide die and diagrams showing methods of attachment of sintered-carbide dies and punches

(*a*) die secured with wedge; (*b*) die secured with clamp plate; (*c*) die press-fitted in case; (*d*) punch fastened with dowel pin and screw; (*e*) punch set in nest and secured with screw; (*f*) punch secured with clamp plate

Chapter 9

Manufacture and Testing of Press Tools

9.1. General Directions for Press Tool Makers

The makers of pressworking dies should strive for high manufacturing and assembling accuracy; high surface finish of mating and shaping surfaces.

These two requirements are interdependent. For instance, high surface finish of punches and dies contributes to their service life, while accurate fitting of punches and dies to one another spells high quality of ready articles and long service life of the tool. If one of the two requirements is neglected, the press tool will be of poor quality. To cite only one example, incorrect heat treatment results in an inadequate durability of the press tool, which will bring to nothing all efforts spent to achieve accurate machining.

Press tooling is subject to heavy loads in operation. These loads vary in values and direction; they are dependent upon the nature of jobs to be performed by the die. For instance, the dies of blanking tools are subject to bending, tensile and shear stresses. The dies in tools intended for backward extrusion are subject to bending and tensile stresses, their punches are subject to bending and compression. The components of press tools will not endure all these stresses unless suitable material has been selected for their manufacture.

Apart from loads arising in work, press tooling is also dependent upon other conditions, such as the cleanness of the material being stamped. Dirt in the form of soil or sand causes abrasion of the working edges in blanking punches and dies or formation of scores on the working surfaces of drawing and bending tools.

The capacity of a press tool to endure a certain number of blanking operations prior to repair or to complete wearout is called the service life of the press tool. The average interrepair life of blanking tools is from 15 to 20 thousand stampings, their total life to complete wearout is from 600 to 800 thousand stampings.

The efficiency of a press tool is enhanced if its design takes into account the specific features of pressworking pro-

cesses (for instance, provision of an adequate taper in the ports of blanking dies).

The life of a press tool depends on the quality of manufacturing, including the mating accuracy, proper heat treatment of the shaping parts of the tool, and finish of the working surfaces on punches and dies. These factors are of special importance in making dies and punches for drawing and backward extrusion.

The cutting tools or grinding wheels employed in machining of press tools leave traces on the machined surfaces. Such traces, in the form of crests and valleys, impair the performance of shaping and mating components.

The direction of traces left by polishing material on the working surfaces of press tools must be parallel to the flow or movement of the material of the stamping. This is especially important for backward-extrusion dies where metal plasticizes and flows upwards over the punch. In this case, cross-wise traces on the die and punch will resist the flow of metal and increase the friction, requiring additional pressure to overcome it. The same refers to the working condition of draw tools. In some cases this may even lead to the separation of the bottom from the workpiece.

Longitudinal traces on the working surfaces of dies and punches in draw tools form lines (notches) on the vertical walls of the workpiece, impairing its appearance.

The correct and stable mating of friction surfaces in press tools depends on the surface roughness of the mating components. The sizes of poorly polished locating surfaces get distorted due to abrasion of crests even after short operation; hole diameters increase and those of a shaft decrease, the slide fit changing to easy slide or running fit, hence lower accuracy.

In tool-making shops, machined surfaces are tested by special instruments allowing accurate estimation of surface roughness; alternatively, a machined surface may be compared to a standard sample of surface finish.

The accuracy of press-tool manufacture should match the accuracy expected from products to be made by the press tool. From this standpoint, all the components of press tooling are classified into two groups:

(1) components taking part in shaping the workpieces

(i.e., dies and punches); those components should meet the most stringent requirements;

(2) structural components whose purpose is to join the components to one another and hold them in their places; those components are made to a somewhat lower accuracy.

The accuracy of various surfaces of press-tool components is usually different for the three following categories:

(a) surfaces or individual elements of a component which have bearing upon the quality of the shape and size of the stamping (die ports, working parts of blanking, drawing and other punches); these components require most labour-consuming and intricate machining methods, they are made most accurately, within very close tolerances;

(b) the mating surfaces that provide for correct positioning of the shaping components in the press tool (joint lines and locating surfaces of sectional dies; locating surfaces of punches and inserts; shaped ports of guides and punch retainers, etc.); in most cases all these surfaces (except for round components) are fitted to size in place;

(c) surfaces and elements of components which do not influence the accuracy of stampings (upper and lower shoes, planes of punch retainers, bases of press tools, etc.); these surfaces are machined to free-size tolerances.

The highest accuracy is required for dies and punches in blanking and piercing press tools, as well as for their guide posts and bushings.

The tolerances for blanking and piercing punches and dies are in intimate correlation with the clearance between them, since looser tolerances lead to larger clearances. Besides, manufacturing and measuring errors depend upon the nominal sizes of the tool working parts.

Hence, when prescribing tolerances for the working parts of blanking and piercing punches and dies, one should proceed from the size of the stamping, its accuracy, the wear likely to occur in the press tool, and the correct clearances between the tool working parts.

Since a worn die produces a larger-than-necessary part, and a worn punch yields a smaller part, the die should be kept within the least possible sizes, and the punch, within the largest possible sizes.

A diagram of tolerances for blanking external contours,

$D - \Delta$, is shown in Fig. 91*a*. The nominal size of the die is taken equal to the smallest size of the part:

$$D_{d\ nom} = D - \Delta$$

The limit sizes of the die (D_d) and of the punch (D_p) will be

$$D_d = (D-\Delta)^{+\delta_d}; \quad D_p = (D-\Delta-z)_{-\delta_p}$$

where D_d and D_p = limit sizes of the die and punch
D = nominal size of the stamping
z = double-side clearance between the punch and die
Δ = tolerance for the stamping size
δ_d and δ_p = tolerances for the die and punch manufacture

Figure 91*b* shows a diagram of tolerances for piercing a hole to a prescribed tolerance ($d + \Delta$). In this case, the nominal size of the punch should be equal to the maximum allowable size of the hole.

The limit sizes of the punch and die will be

$$d_p = (d+\Delta)^{-\delta_p}, \quad d_d = (d+\Delta+z)_{+\delta_d}$$

where d_p and d_d = limit sizes of the punch and die
d = nominal size of the hole to be pierced
Δ = tolerance for the hole to be pierced
δ_p and δ_d = tolerances for punch and die manufacture

The tolerances for punch and die manufacture are found from the tables of tolerances related to nominal sizes according to Class 2 accuracy. In stamping of very accurate parts (Class 2 accuracy), the tolerances for punch and die manufacture are taken according to Class 1 accuracy.

Separate manufacture of dies and punches according to their limit sizes is possible only in case of a round-contour stamping made to Class 4 accuracy. This is why only one member of the press tool is made to the calculated data (the die for blanking and the punch for piercing), while the other member is made by fitting it to the first one with the required clearance.

If the punch is made to the calculated sizes, the die must be finished according to the impression of the punch plus the required clearance.

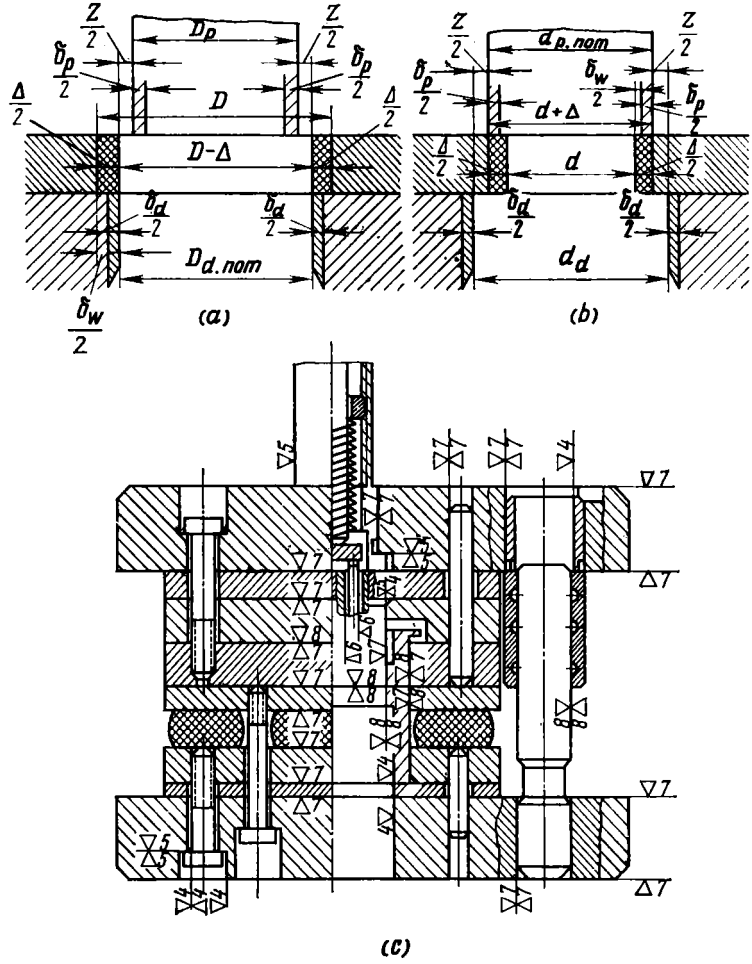


Fig. 91. Tolerances for punch and die manufacture

(*a*) for blanking external contours; (*b*) for piercing holes; (*c*) classes of surface finish for basic components of press tool

In blanking, the clearance is obtained by decreasing the size of the punch; in piercing, by increasing the hole in the die.

In closed-type press tools (with a fixed stripper), the sizes of the pierced hole decrease when the part is removed from the punch. The amount of this reduction depends upon the elasticity of the stamping material.

When a press tool is made without tool drawings, the tolerance for making the punch or die is taken to be 25 per cent of that for the stamping. In this case, clearances are prescribed, proceeding from the thickness and hardness of the stamping material, according to Table 7, the geometrical parameters of dies are taken from Table 8.

When a die is required for blanking or piercing non-mating parts, where the tolerances need not be directed into the material of the part, the nominal size of the die (or of the punch, in case of piercing) is taken equal to the nominal external size of the part (or of the hole as the case may be); the punch or die is made to Class 4 accuracy. The required clearance is obtained by fitting the die to the punch or vice versa.

The suggested surface finish of press-tool components is as follows:

(1) non-working surfaces of components, i.e., those which contact neither the work, nor other components (smooth parts of screws and holes for them; holes drilled in dies and lower shoes) should have Class 4 finish;

(2) non-critical bearing surfaces (bearing surfaces of screws, shank surfaces contacting the press slide) should have Class 5 finish;

(3) fixed joints between punches and round and non-round punch retainers, made to Class 3 accuracy (holes for punches in punch retainers; surfaces of knockout pins; fixed joints between punches and pilots; contacting surfaces of shoes) with the die-to-punch clearances over 0.05 millimetre should have Class 6 finish;

(4) fixed joints of round components made to Class 2 accuracy (joints of a round punch with the punch retainer; joints of dowel pins, rests, guide posts and bushings; contacting and bearing surfaces of a die set, knockouts, stripper, and shoes) with the die-to-punch clearances under 0.05 millimetre should have Class 7 finish;

Table 7

Double-Sided Clearances of Blanking and Piercing Press Tools

Stock thickness, mm	Clearance, mm		Stock thickness, mm	Clearance, mm	
	minimum	maximum		minimum	maximum
Up to 0.3	0.01	0.02	2.8	0.22	0.32
0.3	0.02	0.04	3.0	0.24	0.36
0.5	0.03	0.05	3.5	0.32	0.46
0.8	0.05	0.08	4.0	0.4	0.56
1.0	0.06	0.10	4.5	0.5	0.68
1.2	0.08	0.12	5	0.6	0.8
1.5	0.10	0.16	6	0.8	1.0
1.8	0.12	0.20	7	1.0	1.3
2.0	0.14	0.22	8	1.3	1.6
2.2	0.17	0.25	9	1.5	1.8
2.5	0.20	0.28	10	1.8	2.2

Notes: 1. The minimum clearances are nominal. The maximum clearances allow for the enlargement due to tolerances for punch and die manufacture.
2. For piercing plain-wall holes, take the minimum tabular holes.
3. For blanking and piercing of soft aluminium up to 5 mm thick, take the minimum clearances: for hard materials, the maximum tabular clearances should be taken.

(5) working surfaces of dies and punches shaping the contour of cut or bent parts, as well as the surfaces of drawing punches, sliding-friction surfaces made to Class 1 or 2 accuracy (movable joints of guide posts and bushings, etc.) should have Class 8 finish;

Table 8

Geometry of Blanking and Piercing Dies

Die with a straight belt			Die with a tapered belt			
T, mm	$\beta°$	h, mm	T, mm	$\alpha°$	$\beta°$	h, mm
Up to 3.0	2-4	3-7	Up to 1.0	10′-30′	2-3	3-5
3-10	3-5	7-12	1-6	30′-1°	3-5	5-10
—	—	—	6-12	1°-1°30′	3-5	10-15

Designations: $\alpha°$ – angle of working taper (per side); $\beta°$ – angle of outlet taper (per side); h – height of cylindrical (straight) or tapered working belt in female die; T – stock thickness.

(6) working surfaces of dies, blankholders, and knockouts for drawing tools; working surfaces of cutting tools used for soft non-ferrous metals and alloys and non-metallic materials; working surfaces of punches and dies of shaving press tools; rolling-friction surfaces in tools with ball-bearing guides; surfaces of movable joints of guide posts and bushings in precision press tools should have Class 9 or 10 finish.

Figure 91*c* shows the recommended surface finishes for the components of a combination die.

9.2. Materials for Press-Tool Components

Press-tool components can be made of different grades of steel, depending upon the purpose, operating conditions, and manufacturing procedure of the press tool.

The efficiency, strength, and dimensional stability of the working parts of the tool depend on the material for each particular type of component and its heat treatment.

Thus, in a tool for sheet-metal blanking, the steel used for punches and dies is expected to possess the following properties:

(a) high strength, since the tool carries heavy pressures and is subject to impact loads;

(b) high hardness, since the cutting (blanking) process cannot be carried out unless the punch and die material is notably harder than the workpiece material;

(c) adequate wear resistance, since long service life of a blanking tool depends upon the degree of abrasion of its cutting edges;

(d) high toughness, so as to prevent crushing of the cutting edges likely to occur due to frequent and heavy impacts;

(e) good hardenability, yielding crack-free material after hardening and an adequate depth of the hardened layer, which allows repeated grinding of the punch and die.

Die steel must also possess special manufacturing properties:

(a) lend itself well to cutting and pressworking when cold and hot;

(b) have good hardenability, allowing high hardness to be obtained with a uniform fine-crystalline structure;

(c) show little sensitivity to overheating, so as to allow hardening at elevated temperatures;

(d) provide for low deformation in heat treatment;

(e) be of low sensitivity to decarbonization when heated, which detracts from the hardness of the working surface layer of metal;

(f) lend itself well to grinding, thus allowing high class of surface finish to be obtained at a high speed of grinding.

The above requirements are met only by a few grades of tool steel.

9.3. Methods of Die Manufacturing

The press-tool manufacturing process includes the following stages:

(1) preparing a blank;

(2) machining the blank;

(3) bench work on the working parts of tools (dies, punches, punch retainers, strippers);

(4) heat treatment of press-tool components;

(5) machine grinding of the heat-treated components;

(6) manual grinding and finishing of working parts;

(7) assembly, testout, and adjustment of press tools.

Operations 3, 6, and 7 are performed by die-making fitters who also take part in machining operations: they perform the marking and interstage fitter's jobs and, in some cases, simple machining operations.

Preparing a blank. When preparing blanks for press-tool components made of carbon and alloy tool steels, the following operations are performed: cutting the material from a block, plate, or strip by means of a circular saw, power hacksaw, or a gas cutter; forging or upsetting; isothermal annealing; planing or milling of planes leaving an allowance of 0.25 millimetre per side; lathe turning to diameter; normalizing of carbon steels or high-temperature tempering of alloy steels; and rough grinding of surfaces. When all this has been done, the blank is finished according to the drawing.

Heat treatment of blanks improves their machinability at subsequent stages, lowers deformation in hardening, and increases the service life of press-tool components. All

blanks, made of rolled stock and forged from alloy and carbon tool steels, are subjected to isothermal annealing.

To eliminate surface stresses arising in rough machining, blanks of alloy tool steels are subjected to high-temperature tempering, while carbon-steel blanks are normalized.

Blanks made of structural carbon steels need fewer operational stages: cutting a blank from the stock, shape forging, planing or milling with an allowance of 0.25-0.30 millimetre per side, grinding surfaces or end faces, and lathe turning to diameter. Next follows finishing according to the drawing.

9.4. Machining of Blanks

Machining of blanks for press-tool components may include the following operations, depending upon the shape and size indicated in drawings: jig boring, contour milling, form planing, hole slotting, lathe machining (turning, boring, finishing, and polishing), cylindrical and internal grinding, surface grinding, shape grinding, as well as electrospark, electro-erosion, and ultrasonic machining of shaped contours and cavities.

There exist several methods for making and fitting the working parts of blanking and piercing tools; the selection of a particular method depends upon the type of production where the press tool will be employed.

In mass and large-lot production of press-tool components, round blanking and piercing punches and dies up to 60 millimetres in diameter, as well as cutting dies and punches of a rectangular or irregular shape, are produced to close tolerances ensuring interchangeability of the parts. In this case, the punches and dies are made separately, the working parts being made to accurate sizes by circular, surface, or profile grinding. The die fitter will perform only assembling operations.

The working parts of dies and punches can also be made by impressing a hardened master punch or master die sized so as to provide for the required clearance. This method is very efficient and ensures a high reproducibility of sizes and shapes in all the dies (or punches). It is, however,

reasonable only for lot production of small intricately-shaped punches and dies.

In large-lot production, non-round blanking tools, as well as medium-size and large round tools, are made by fitting the punch to the die (for blanking tools) or the die to the punch (for piercing tools), observing the prescribed clearances.

In small-lot production, press tools are made individually (as single pieces); in this case a green die is machined to an impression of a hardened and finished punch (for blanking tools) or a green punch is impressed by a hardened and finished die (for piercing tools). This method is most frequently used in making tools for stamping materials up to 0.5 millimetre thick. As the cutting edge wears down, the green die (or punch) is caulked.

When making punches and dies for blanking of small and medium-size intricately-shaped parts, as well as in making solid carbide dies, the working part of the punch or die is made of hardened material by electromachining with subsequent finishing by diamond tools.

Process planning. When designing the process of tooling manufacture, use is commonly made of the system employed in single-piece production. The manufacturing process is not worked out in detail, but only the most reasonable sequence of operations is indicated. For fabrication of critical parts, special-purpose tools are listed, and also are methods for inspecting the finished parts, specific methods of their testing, permissible deviations from the prescribed accuracy at various stages of the process and surface roughness after intermediate operations.

When working out the manufacturing process, the most important point is to select the sequence of individual operations so as to ensure the datum surfaces, facilitating further processing and serving as the reference for taking all the dimensions of the part.

Taken as such datum surfaces may be those surfaces of a part that define its position with respect to the cutting tool in the course of its manufacture: external or internal surfaces of the part, centring holes, etc.

Datum surfaces are classified into main and auxiliary ones.

The main datum surfaces are the design surfaces that orient the component in the die. For example, the side surfaces of a female die may serve as the datum surfaces for the die walls (Fig. 92*a*). When the die is installed on the table of a machine-tool, its position is adjusted with respect to its bottom plane, lying on the machine table, and two of its side planes (e.g., *A* and *B* or *C* and *D*) are located so that the dimensions h and h, as well as h_1 and h_1, are pairwise equal. This ensures more accurate dimensions and position of the die with respect to the components mating with it: the punch retainer and the stripper.

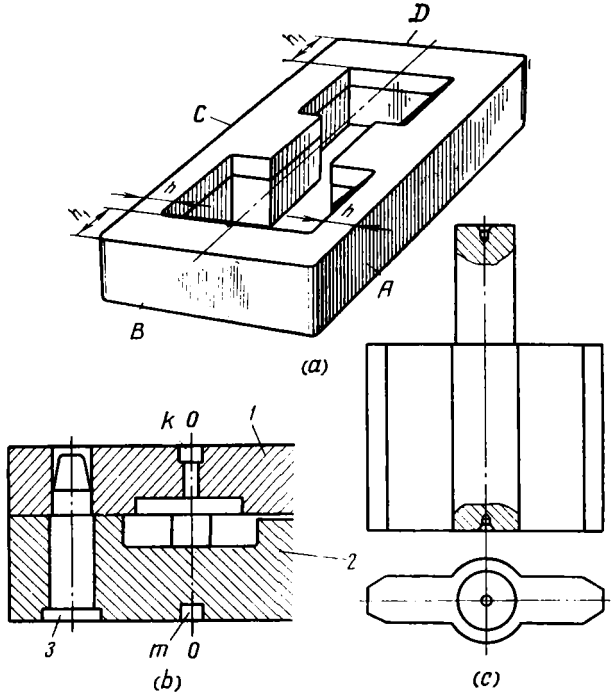


Fig. 92. Selection of method for making the shaping cavity of a female die

1—punch; *2*—female die; *3*—guide posts

The auxiliary datum surfaces are those provided in the course of fabrication for the purposes of more accurate machining.

For instance, in machining the mating components of a die for pressing and forming a part in both sections of the die, the die sections being aligned solely by means of guide posts, machining is facilitated and accurate alignment of the die impressions is ensured by locating holes *k* and *m* bored in the bottoms of punch *1* and female die *2* (Fig. 92*b*) along the axis 0-0. This operation is carried out on a jig borer. At the same time, the holes for guide posts *3* are bored. When machining, the die section is mounted with the locating hole on a pin provided in the centre of the indexing table (in milling) or on a special arbor set in the machine spindle (in turning). This results in a very accurate alignment of the conjugated shaping cavities.

For machining a shaped punch on milling, slotting, and grinding machines, a locating shank and centring holes should be provided at the end faces as shown in Fig. 92*c*. The shank of the punch to be machined is secured in the machine chuck so as to allow the withdrawal of the cutting tool; the other end of the punch is supported by the tailstock.

The sequence of operations in die manufacture should make maximum use of all the capabilities of machine equipment, thereby minimizing manual fitting operations. Suffice it to say in this connection that milling an allowance of 0.1-0.2 millimetre left in a blind cavity of a die down to 0.02-0.03 millimetre over an area of 50-60 square millimetres takes 10-12 minutes, while the same effect is achieved manually by a skilled fitter in 90-100 minutes.

One and the same component can be made by various manufacturing methods; the selection of a method depends on the economical and technological factors active at a particular enterprise.

Let us analyse a few methods that can be used to make a blanking punch shown in Fig. 92*c*. This punch can be made:

(1) by planing on a shaper after marking done by a fitter on a bench plate or according to the contour of the die hole, with subsequent manual filing;

(2) by milling after marking with subsequent manual filing according to the die;

(3) by machining on a form planer with manual filing according to the die;

(4) by rough machining after marking with subsequent heat treatment and form grinding with a profiled abrasive wheel;

(5) by rough machining after marking on a planing or milling machine with subsequent heat treatment and grinding with a conventional abrasive wheel on a surface grinder with the work mounted in an indexing head and supported in the centre.

None of the first three methods obviates the need of laborious fitting operation, that of filing the punch prior to heat treatment. Besides, the deformation that may occur in heat treatment will reduce all the work done to naught.

Unlike these three methods method (4) is economically more reasonable, since it eliminates precision machining of the punch and makes it unnecessary to perform the most labour-consuming operations, those of manual fitting of the punch prior to, and following, heat treatment. On the other hand, this method calls for a diamond dressing tool and much time for mounting and re-mounting the punch on the table of the grinder.

The most efficient is method (5) allowing, as it does, the employment of a conventional abrasive wheel and the machining of the work with one setup in an indexing head. Such a setup also makes it easier to inspect the dimensions and shape of the punch and its fitting to the die opening in the process of grinding. The die-making fitter's only concern is to dress the chamfers and trim the burrs.

When making structural die components, the work usually begins with jig boring. This operation is performed on jig borers according to calculations wherein all linear dimensions of the working profile are given in a rectangular system of coordinates and laid off from a common datum surface.

When round working holes must be bored in press-tool components, the coordinates of their location, found with reference to the common datum, are given in hundredths

(sometimes in thousandths) of a millimetre. Taken as the origin of coordinate axes Ox and Oy is the centre of the most important working hole or the geometrical centre of the blank, in some cases this purpose is served by a ground lateral side of the blank. Figure 93*a* shows an example of calculation of coordinates for rectangular components.

To make auxiliary holes on the blank (such as those for obtaining a working contour with a radial conjunction, shown in Fig. 93*b*), the diameters of the auxiliary holes are taken equal to the double radius forming the working figure (holes d and d_1) minus an allowance for further machining.

In conjugations with no radius, the diameters and coordinates of the holes are taken so that the hole generatrix be tangent to the generatrix of the working figure (see Fig. 93*c* and *d*).

The coordination of relative arrangement of all the elements in the component results in a higher accuracy, a better quality of machining, and a shorter manufacturing time.

In the process of milling, slotting, grinding, and bench fitting, the surfaces of the profile ports are kept tangent to the bored holes, thus minimizing the number of measurements taken in the ports themselves and between them (one should only control the straightness of surfaces being machined and produce the required draft in die ports so as to allow for removal of the blanked component or slug).

The manufacture of tools for blanking components of an intricate geometrical shape often starts with machining the die. After the die has been hardened and finished, the punch is fitted to it to serve later as a reference for machining the shaped ports of the punch retainer and the stripper.

This sequence of operations is not compulsory for shops equipped with profile-grinding machines or special attachments for profile grinding on general-purpose grinding machines. In this case, the punch is made first, the die is fitted to it, and then the holes in the stripper and the punch retainer are provided.

This method is advantageous in obviating the need of making shaped templets and broaches for machining the shaped port in the die, which makes it unnecessary for the

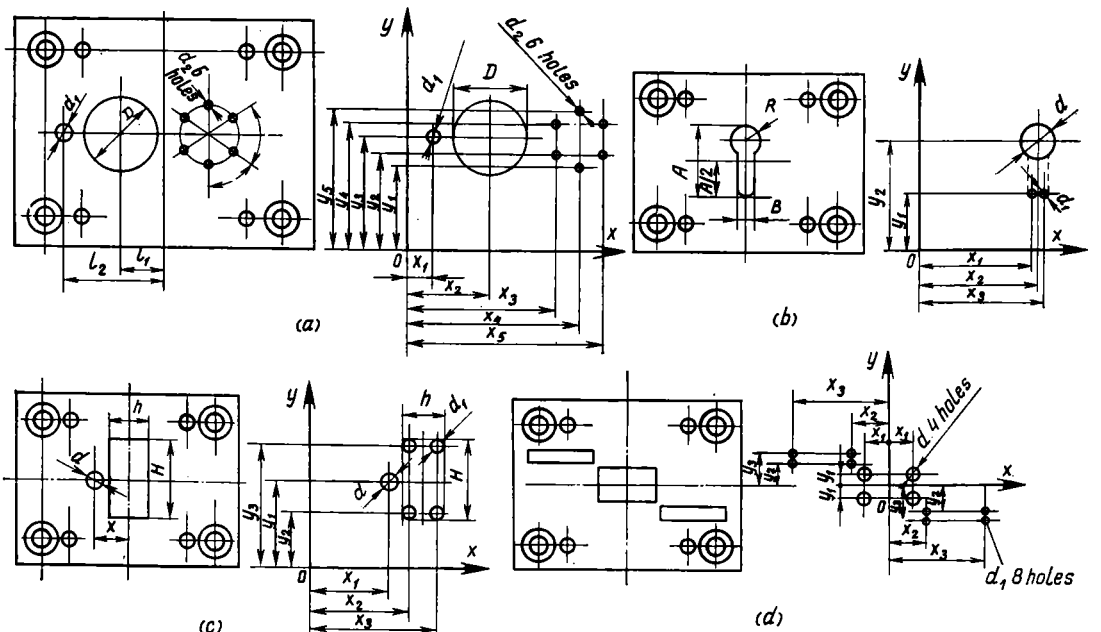


Fig. 93. Examples of coordinate plotting of hole locations

(*a*) from the centre of a base hole; (*b*) and (*c*) from the lateral and bottom sides of the blank; (*d*) from the geometrical centre of the blank

fitter to take frequent and time-consuming measurements. Besides, the fitting process itself becomes more simple, since the geometrical shape and dimensions of the hardened and ground punch are in strict conformity with the drawing, which eliminates the necessity of taking any more measurements in the shaped port. The fitting process is reduced to the following: an impression is made by the ready punch on the rough-machined die, then the port is slotted, milled, and filed according to the impression. If necessary, another impression is made by the punch and the die is finish-fitted to the punch which, in this case, is used as both the drift pin and the templet.

All this speeds up the manufacture of press tools.

However, this method has a limitation: the die deforms during heat treatment; remedying the faults and finishing the hardened die to suit the punch may take more time than finishing the punch to suit the finished die.

Therefore, efficient use of ground punches for finishing the dies depends on an ample selection of tool steel grades with low deformation in hardening. Besides, heat-treatment facilities of the shop are expected to be very good.

The above sequence of operations in machining press-tool components is not the only one possible. It can vary depending upon the complexity of the component, its design, the shape of the working sections, the accuracy required, the number of similar components manufactured in a batch, and other factors.

The machining sequence greatly affects all the rest of the manufacturing process, influencing the accuracy, quality and efficiency of work. It is not seldom that the machining sequence depends on the equipment and different devices available in the shop for mechanizing labour-consuming fitter's jobs.

After deciding upon the sequence for manufacture of press-tool components, the next step is to establish the order of machining their individual elements.

When selecting a particular method for manufacture of a press tool two basic rules concerning the machining sequence should be adhered to:

(1) first machine the components whose profile and relief (in shaping tools) can be obtained on machine-tools;

(2) next treat the mating components manually, comparing their profile to the actual sizes of machined workpieces.

Always start with the components of intricate profile, which are likely to deform during hardening. Leave an allowance for fitting the components to size in assembly.

Taken as the manufacturing datum surfaces are usually the cylindrical or end surfaces of the workpiece or three mutually perpendicular planes. In the manufacture of press tools one has sometimes to violate the principle of taking constant datum surfaces, since, at a certain stage, further machining may call for new datum surfaces. This may be the case when shaping the die or stripper according to the punch impression: the datum surfaces used in the first operations performed upon the die are replaced by new ones, since the profile obtained in accordance with the impression may fail to be parallel to the previously machined datum surfaces of the component. Therefore, for further machining the position of the datum surfaces or the arrangement of other holes should be brought in agreement with the surfaces of the profile, taken as new datum surfaces.

If there are no convenient datum surfaces in a die or punch, special locating holes are made on a jig borer.

Machining precision holes can be done with the aid of drills and reamers on precision drilling or vertical-milling machines. The most accurate holes are made on jig boring machines.

In hardened components, holes are made by carbide or diamond tools; grinding is also resorted to.

Shaped holes and holes in difficult-to-machine materials are obtained by electromachining and ultrasonic methods.

The machining method is selected to suit the properties of the material and to produce the required accuracy, surface finish, and hole shape.

Cylindrical holes of Class 4 accuracy and Class 5-6 finish are drilled and reamed or bored.

To obtain a hole of Class 3 accuracy and Class 6-7 finish, drilling is followed by reaming or fine boring.

If Class 2 accuracy and surface finish better than Class 7 are required, the drilled and bored holes are machined with roughing and finishing reamers.

Holes in hardened components are machined by grinding or diamond boring. Extra-precision holes are finished by lapping.

9.5. Benchwork Performed on Female Dies

In the manufacture of dies for pressworking tools, the most difficult job is that of making the working shape of the die.

Making dies for stamping round parts does not involve manufacturing difficulties. The annealed blank is turned and bored on a lathe, then hardened and finished on a surface grinder, a circular grinder, and an internal grinder.

Making dies for non-round stampings is much more difficult. This job calls for more operations performed on different types of equipment and manually.

Normally the benchwork upon dies of blanking tools starts with profiled ports, after which the rest of members are dealt with. The first to be treated are the most critical and intricate members of the die, those bearing upon the geometrical shape and dimensions of the future stampings; these are followed by the rest of the elements, while the finished surfaces are taken as datum ones.

As an example let us consider the sequence of treating a die shown in Fig. 94*a*. The manufacture of the die involves the following operations:

(1) planing a blank to size 210 × 44 × 30 millimetres with a grinding allowance of 0.25-0.3 millimetre;

(2) finish grinding the bottom and top surfaces;

(3) grinding two side surfaces at an angle of 90°;

(4) drilling and jig boring two 12-millimetre holes in the centres of the 6-millimetre radii, two 8-millimetre holes in the centres of the 4-millimetre radii, two holes $4^{+0.01}$ millimetres in diameter, four holes $10^{+0.02}$ millimetres in diameter, and four holes 10.5 millimetres in diameter;

(5) marking the die port profile;

(6) milling the die port to marking, leaving an allowance of 0.05 millimetre per side;

(7) bench fitting the die port profile for subsequent hardening;

(8) hardening and tempering;

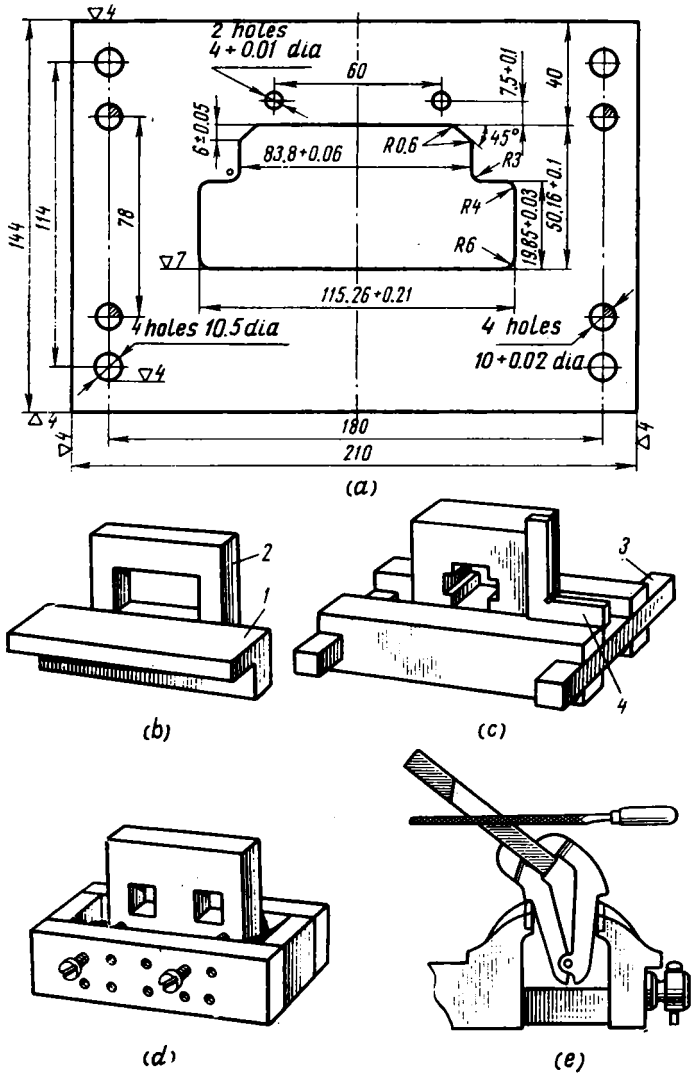


Fig. 94. Blanking die and jigs for manual filing of profiled ports
(*a*) die; (*b*) filing square; (*c*) filing jig parallels; (*d*) universal jig with screw-clamped workpiece; (*e*) angular vice; *1*—filing device; *2*—workpiece; *3*—guide blocks; *4*—test square

(9) finish grinding the bottom and top surfaces;
(10) finishing the die port to size and shape.

The above list of jobs testifies that the benchwork is responsible for three most complicated and critical operations: marking the die port profile, filing the latter for hardening, finishing the port of the hardened die to obtain final size and shape.

The die port profile may be marked proceeding from the drawing or from a templet which subsequently will be employed in filing the die working contour.

The die port profile can be prepared for hardening on a filing machine or manually. To make the benchwork easier, use is made of different tools and jigs, such as filing squares, jigs, adjustable filing frames, etc. (Fig. 94*b*, c and *d*).

These tools and jigs are essentially aimed at facilitating the job of filing the surfaces observing the required accuracy. In such cases the work is secured in the jig and then clamped, together with it, in a vice. In the course of filing, the hardened and precision-ground working plane of the jig pilots the file or lap and thus reduces the possibility of removing too much stock.

Filing tools and jigs can be employed for different filing jobs. Thus, a filing square is applicable for all filing jobs, but its one-sided wing makes it difficult to obtain a true plane on workpieces thicker than 5 millimetres. More convenient are filing jig parallels with tight-fitted but movable guide plates. The plates can be moved apart over the guide blocks to suit the thickness of the die to be filed. The die is mounted between the plates, its position verified to the datum surfaces, and the jig with the work is clamped in a vice. Such frames are used for work in the ports of punch retainers, strippers, guide plates, cases, and other components; they are also suitable for filing the profiles of templets which are later on used for finishing profiled die ports.

For filing the ports in the dies of blanking press tools, use is made of filing jigs with fixed filing plates and screw clamping of the workpiece. To increase the versatility of such frames, their filing surfaces are ground at one side at an angle of 90° to the internal surface and at an angle of

89°30′ at the other side, which allows their application for filing a draft of 30′ in the drop-through clearance of blanking and piercing dies.

For handling the drop-through clearance in the ports of dies with a large clearance angle, where the accuracy and flatness of walls are of minor importance, an angular vice can be used which is clamped together with the blank in a bench vice (Fig. 94*e*).

Making ports in female dies. Die ports are most often profiled with the aid of punches. The punch used for the purpose may be either the one to be employed in the press tool, or a specially-made master punch, or else a standard item stored in the toolroom.

When the press-tool punch is used, it must be in the finished state. The punch is placed on the surface of the green die with a roughly machined port and forced by a press into the profiled port to a shallow depth. Then the clearance of the port is filed out and the port shape and the punch-to-die clearance are adjusted using the punch as a templet.

If an enterprise has to manufacture every year several identical press tools for making the same part, use is made of special master punches that include the punch-to-die clearance. Application of such punches in repeated manufacturing of dies largely accelerates the work and ensures press tools of high quality.

Standard punches can be used for both making separate elements of shaped die ports and profiling the entire port.

When punching a port in a die, it is very important that the punch should be dead perpendicular to the datum surface of the die blank. This is usually tested by a try square or, alternatively, the punch is brought in contact with a box (a V-block) with precision angles. For convenient and quick punching of dies, the device shown in Fig. 95*a* may be used.

The device comprises top plate *4*, base *6*, and posts *5* attached to one another by screws *1*. In the centre of the top plate there is a bored hole which receives adapter bushings *2* with an inside diameter corresponding to the diameter of the punch shank. Die *7* is mounted in the device, then punch *3* with a guide is inserted through bushing *2*.

Striking with a hammer against the punch (or using a press for the purpose) produces an impression or a through hole.

The posts of the device should be perfectly equal in height. If dies of different height are to be punched, replaceable posts should be resorted to.

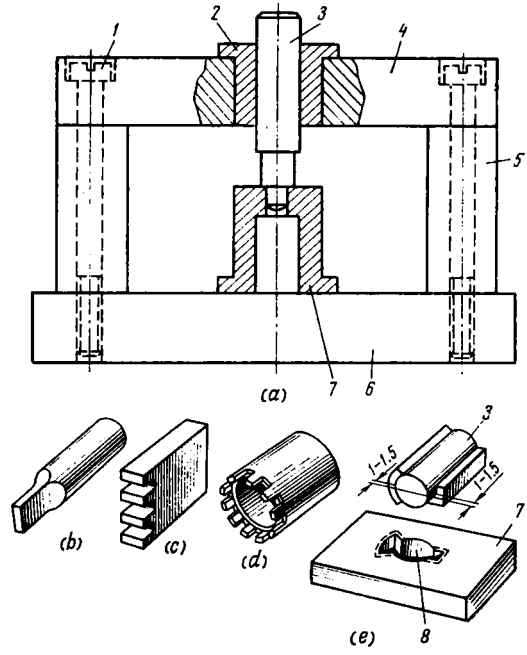
Punches may be designed for making one or several ports at a time. The punches for making many ports at a time are complicated and, therefore, find applications only when an accurate positioning of the ports is of critical importance. Figure 95*b* shows a single-slot punch; Fig. 95*c*, a rectangular stepped punch; Fig. 95*d*, a stepped punch for slots arranged along a circumference. The latter two types of punches are used both for making an initial rough impression 0.5 millimetre deep and for final sizing. Intermediate punching is performed only by single-slot punches.

Profile marking on the surface of a die and precision punching is a complicated operation. Application of the method described in Fig. 95*e* considerably accelerates and facilitates the operation. First, several plane and cylindrical surfaces of the profile of port *8* are machined in die *7*, then these members are used as guides for the punch or for obtaining an impression of the punch. In punch *3*, a layer of stock 1-1.5 millimetres thick is ground off from the working face, leaving intact the guide areas which ensure the correct position of the punch in the guide hole of the die when producing an impression. After the die is ready, the projection on the punch is ground away.

Figure 95 (*f* and *g*) shows the dies for progressive press tools intended for blanking a plate with a hole in the centre and several square holes spaced over a circumference.

The positions of all holes are coordinated on a jig borer on which round holes are drilled and bored to a diameter equal to the side of the square. The die of Fig. 95*f* has an even number of square holes (8 holes), while that of Fig. 95*g* has an odd number of holes (9 holes). In the former case, the even number and symmetrical arrangement of square holes allows the following method to be applied.

Hardened steel punches *3* are inserted in two opposite holes in die *7* (Fig. 95*h*). For their surfaces to be parallel to the axis of the central hole in the die, the punches are clamped in holder 9 (screw clamp) with plates *10* forced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2
3
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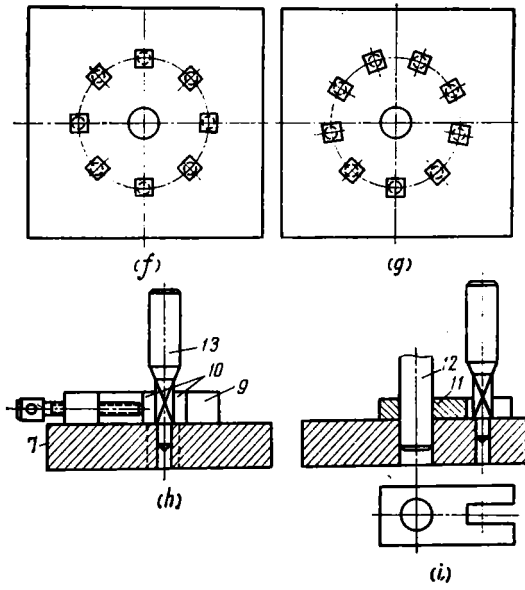
(f)
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(i)

together by the holder. The impression on the die is made by striking with a hammer against the punch head or by driving it with a hand-operated screw press until an impression 0.5-1 millimetre deep is formed. Since the punches are held between the two plates, they remain parallel, and the correct direction of the impression is thus preserved.

With an odd number of square holes this method of punching becomes inapplicable, since the sides of the squares facing the centre are not parallel to each other. In this case, the correct orientation of the punch is achieved with the aid of templet *11* (Fig. 95*i*) having a hole whose diameter is equal to that of the central hole bored in the die. One side of the templet has a ground central slot of a width equal to the side of the square in the die.

For obtaining an impression, the templet hole is aligned by plug *12* or a gauge with the central hole in the die, and guided punch *3* is inserted in the hole bored in the place of a square, the slot in templet *11* providing for the correct position of the broach. Depending on the size, an impression is made or a hole is pierced through.

Further processing involves finishing the square hole and bevelling and sizing the port by a sizing broach, taking into account the clearance to be left between the punch and die.

Another method of making holes is as follows. The hole is first slotted or milled on a vertical milling machine, leaving a minimum allowance for broaching. Broaching is normally done in a guide, using several broaches consecutively, the size of each successive broach exceeding that of the preceding one by 0.1-0.15 millimetre. The final sizing is done by full-profile broaches.

Fig. 95. Tools and methods of punching profile ports in female dies

(*a*) punching device; (*b*), (*c*), and (*d*) variants of punches; (*e*) using the finished punch of a press tool, aligned by the finished section of the die hole; (*f*) die with an even number of holes; (*g*) die with an odd number of holes; (*h*) punching with the aid of a screw clamp and guide plates; (*i*) punching with the aid of a special templet; *1*—screw; *2*—bushing; *3*—punches; *4*—top plate; *5*—post; *6*—base; *7*—dies; *8*—port; *9*—holder; *10*—plates; *11*—templet; *12*—plug

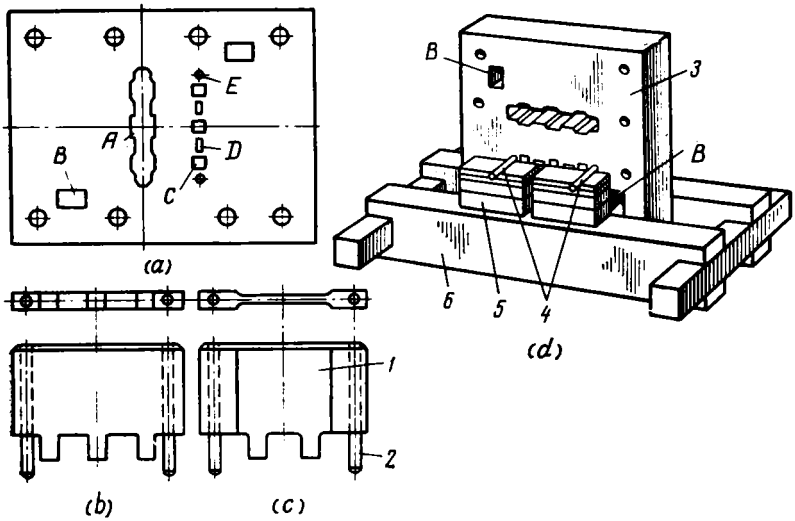


Fig. 96. Manufacturing dies with several ports of different profiles
(*a*) die; (*b*) punch for three square ports; (*c*) punch for two rectangular ports; (*d*) filing blade ports; *1*—punch; *2*—pin; *3*—die; *4*—sized rod; *5*—gauge blocks; *6*—jig

Let us consider the manufacture of a die with several ports of different profiles, spaced at distances with close tolerances (Fig. 96*a*).

Such a die can be machined by two methods. One method involves the following operations. A jig borer makes holes in shaped port *A*, in blade ports *B*, and in pierce holes *C*, *D*, and *E*, thereby positioning them with respect to one another. After milling and slotting, the component is handed over to the fitter.

The other method is as follows. First, shaped port *A* is coordinated and finish-machined (including the fitter's jobs). Then it is taken as the datum surface when the die is mounted on the jig-boring machine to bore the rest of the holes.

In the first method, presuming simultaneous coordination of all the working elements of the die, the fitter who treats shaped port *A*, should closely maintain the prescribed distances between the shaped port and the other

ports. Even a slightest departure of an axis from its position will lead to a lower quality of the stamping which will have unequal sides.

Machining to coordinates may fail to yield good results, since the holes are usually made 0.1-0.05 millimetre smaller than the specified dimension of the shaped port. Besides, some sections of the ports may be machined oversize, so that the fitter will have to correct the geometry of the figure by shifting the entire contour of the port to one side or another.

The second method facilitates the fitter's work. The fitter need not be concerned with any dimensions except for those of the shaped port; he makes an impression by a punch in the shaped port, slots it on a machine, and files it by hand to the impression of the punch. All further machining operations are based on the finished shaped port.

Figure 96 (*b* and *c*) shows special punches that allow the correct position of square and rectangular holes to be obtained. The punch (Fig. 96*b*) is intended for three square ports, and the punch (Fig. 96*c*) is for two rectangular ports. Punches *1* are located by two cylindrical pins *2* introduced in holes *E*. These punches are used only for making the first impression 0.5-0.7 millimetre deep, which determines the position of the holes, their shapes and sizes. Now each hole is finally treated with standard punches.

Ports *B* for blades are filed in a jig. A jig convenient for filing rectangular ports in the die under consideration is shown in Fig. 96*d*. The tracing surface of the jig is so located as to ensure the required distance from the port wall to the axis of the round centre holes (in this case, holes *E*) made on the jig borer; this effect is expected when the file just touches upon the tracing surface of the jig.

The position of die *3* is adjusted with the aid of sized rods *4* inserted in holes *E*; gauge blocks *5* are employed to inspect the die position in filing jig *6*. The jig with the die is clamped in a vice, the rods are removed from the holes, and one side of blade port *B* is filed. This side of the port serves as the datum surface for filing the opposite side of the port, the size of the port being inspected with gauge blocks.

The other blade port is filed in the same way.

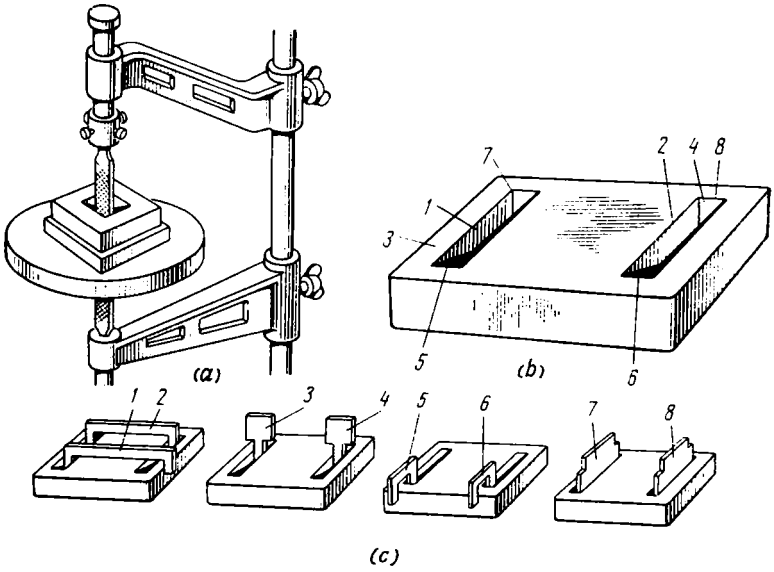


Fig. 97. Machine filing of die ports

(*a*) arrangement of the workpiece and the file; (*b*) machining sequence; (*c*) measuring the dimensions and checking the parallelism of port walls; *1-8*—surfaces being machined

Shaped ports in dies are first drilled irrespective of the shape, then machined on a slotting machine or milled with an end mill to marking, next the walls are filed by hand or on a filing machine.

For drilling long and narrow ports, the centres of drilling are marked out according to the drill diameter which is chosen to leave an allowance for further machining of the walls (0.2-0.3 millimetre per side). To prevent the drill from deviating towards the previously drilled hole, each drilled hole is filled with a piece of round steel rod of the appropriate diameter. When drilling is over, this piece of metal is knocked out, then turned with its intact side towards the next hole to be handled, and forced into the just drilled hole, the drilling procedure is recycled.

The webs between the drilled holes are chipped off by a cape chisel or a punch, the walls are filed by a tool of the corresponding shape and size.

A more efficient method of machining ports in blanking dies prior to heat treatment consists in filing the walls on a filing machine (Fig. 97*a*).

The sequence of making rectangular ports on a filing machine is as follows. The filing allowance (0.2-0.3 millimetre per side) is first removed by a flat file, then a square or triangular file is used to machine the corners. First surfaces *1* and *2* (Fig. 97*b*) are filed by a flat file, then the workpiece is turned through 180° and surfaces *3* and *4* are filed in the same way. After this the flat file is replaced by a square one and surfaces *5*, *7* and *6*, *8* are filed.

The port dimensions are tested by a slide gauge, gauge blocks or snap gauges and templets (Fig. 97*c*).

Grinding the die ports. When no special-purpose grinding machines are available, closed-outline ports in dies can be ground on a universal tool grinder or on a horizontal spindle surface grinder. For this purpose the machine spindle is to be fitted out with special arbors for attaching abrasive wheels.

Under usual speeds of the spindle in a grinding machine (normally designed for wheels 80 millimetres and over in diameter) small-diameter wheels will run under slow peripheral speed and, consequently, cut poorly and wear out rapidly. For the grinding process to be satisfactory, the spindle should run under the highest possible speeds. If possible, the revolutions should be speeded up by means of change or step pulleys mounted on the machine spindle drive.

Die *1* (Fig. 98*a*), subject to internal grinding, is first ground over the external surfaces to an angle of 90°, then it is mounted on a tool grinder for machining holes or slots. The die can be mounted right on the machine table or on sliding angular plates *2* as is shown in the figure. Parallelism of the work mounting with the direction of the table longitudinal travel is checked with a dial indicator.

The closed outlines are ground in two stages. First, the walls are treated with a grinding wheel whose diameter is more than twice the corner radius of the port. By cross-feeding the table, the wheel is introduced into the blank port, and the table dogs are set so as to allow but a slight

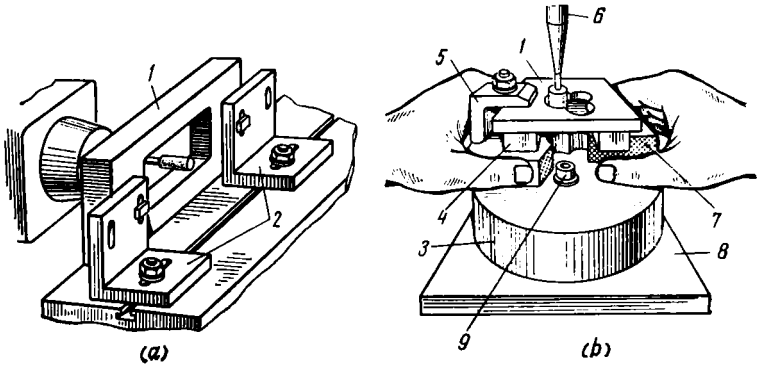


Fig. 98. Jig grinding of closed ports in dies
(*a*) rectangular port; (*b*) shaped port; *1*—die; *2*—angular plates; *3*—auxiliary table; *4*—spacers; *5*—cramp; *6*—spindle; *7*—templet; *8*—machine table; *9*—tracing roll

contact of the wheel periphery with either of the two vertical surfaces in the port when the table is in its extreme right-hand or left-hand position.

The final grinding is performed with a wheel whose diameter is equal to twice the corner radius of the port. If the corners of the port being ground develop a projection (due to springback of the spindle when loaded), they should be ground several times by cross-feeding the table till the transition from the radius to the straight plane becomes quite smooth.

Shaped-contour ports in green dies are also often ground by a method which consists in cam-contour grinding to a templet with the die manually fed against the grinding wheel.

For this purpose, a vertical-spindle surface grinder or a high-speed bench drilling machine is adapted. Replaceable tracing roll *9* (Fig. 98*b*) is mounted in coaxiality with grinding spindle *6* on machine table *8* or an auxiliary table *3* attached on table *8*. The roll diameter must be equal to the diameter of the grinding wheel. Therefore, a set of rolls is manufactured with diameters differing by 0.5 millimetre so as to suit various sizes of the ports in dies to be machined.

The grinding operation is performed with the aid of plastic templet *7* whose cavity corresponds in the outline and the size to the port in the die. The templets are replicas of finished punches, made of a quick-setting plastic.

Rough-machined die *1* is secured by cramps *5* with spacers *4* on the plastic templet so that the outlines of the die and the templet coincide. The grinding wheel is dressed with diamond and, after measuring the wheel diameter, a roll of the appropriate diameter is mounted on the table. The roll running over the templet will accurately follow the templet profile and the grinding wheel will remove the allowance in the die port in full conformity with the templet.

The entire grinding allowance can be removed in a few passes. This is why the first passes use rolls with a diameter somewhat larger than that of the grinding wheel, whereas subsequent passes are performed with rolls of smaller diameters, which ensures the wheel infeed.

A set of replaceable rolls allows the application of the same templet for removing the stock by manually moving the work over the templet profile, compensating for the wheel wearout, grinding with an allowance for finishing the work after hardening, and providing a uniform punch-to-die clearance.

9.6. Manufacture of Sectional Dies

Dies with an intricate outline of the shaped port are often made sectional, that is, composed of several parts which can be easily machined after hardening, assembled, and enclosed in a non-hardened steel case.

An example of fabrication of a sectional die is shown in Fig. 99 (*a* and *b*), from which one can easily see the advantages of such a design for the die manufacture. The die shown in Fig. 99*a* can only be made by fully machining the port profile prior to hardening, followed by elimination of deformations and by finishing, whereas the die shown in Fig. 99*b* can be easily machined after hardening by grinding it on a standard surface grinder or a tool grinder.

The die shown in Fig. 96 can also be made in the sectional form to consist of two symmetrical halves mating along the axis of the intricate-shape port.

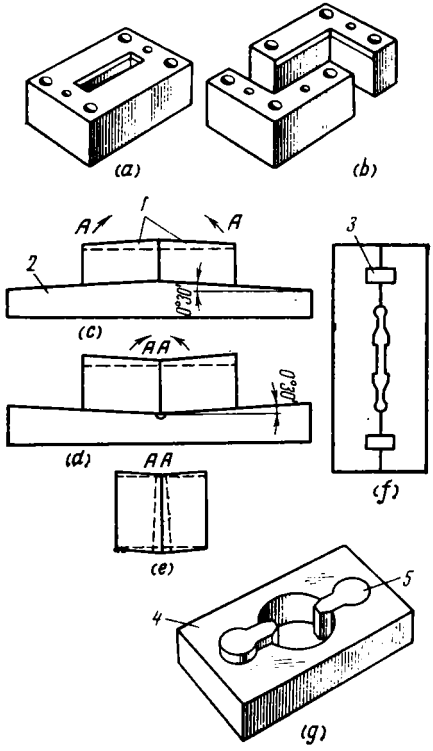


Fig. 99. Methods of manufacturing of sectional dies

(*a*) integral die with a rectangular port; (*b*) the same die of sectional design; (*c*), (*d*), and (*e*) methods of grinding die halves; (*f*) sectional die with an intricate-shaped port; (*g*) die with inserts; *1*—die halves; *2*—pad; *3*—key slots; *4*—die; *5*—inserts

Figure 99 (*c* and *d*) shows a pad for machining die halves *1* before and after heat treatment. The upper surface of pad *2* is bevelled at an angle of 30′ outwards (Fig. 99*c*) or inwards (Fig. 99*d*). These bevels allow the working draft of the profile port to be obtained in the die.

The latter method (Fig. 99*d*) offers more convenience, since the joining of the two halves (as shown by the arrows) does not result in parting of their working edges *A-A* from each other, as it does in the former method (Fig. 99*c*). This, in turn, ensures a very accurate mating of the die halves

over the entire outline of the port. When machining the dies on the convex pad, the abrasive wheel somewhat cripples the profile being machined in places of the wheel entrance into, and exit from, the workpiece metal. This somewhat detracts from the mating accuracy of the die halves.

After the die has been heat-treated, the working contour in both die halves is ground on a surface grinder, using the same pad. In the same setup, two slots *3* (Fig. 99*f*) are simultaneously ground in the two die halves. When the die is assembled and enclosed in the case, two ground keys will be press-fitted into these slots to provide for correct mating of the die halves.

Since, after joining the die halves, their upper and lower surfaces will not be parallel, the assembled die is to be ground over these surfaces (as shown by a dotted line in Fig. 99*e*) to form an angle of 90° to the side surfaces.

A die with two projections in a cylindrical port, shown in Fig. 99*g*, can be best made by press-fitting two inserts. The round port in die *4* and two ports for inserts *5* are made prior to hardening with a moderate allowance for grinding the round section of the port and press-fitting the inserts.

The inserts are fitted to the punch when green. After heat treatment, the shaped port of the die is machined to the required size on an internal grinder, the hardened punches are ground over their working parts and forced in place. After the inserts have been press-fitted, the port profile is tested with the punch, and the upper and lower surfaces of the die are ground on a surface grinder.

Figure 100 shows a press tool for blanking E-shaped transformer laminations. Making integral dies and punches for blanking electrical steel involves many difficulties, since these press tools have very small punch-to-die clearances (0.01-0.03 millimetre) and their linear dimensions must be kept to close tolerances. Besides, the shape of the punch and die is of such a kind that they are liable to deform during heat treatment.

These shortcomings may be eliminated by making sectional dies and punches, such as shown in Fig. 100. The punch (Fig. 100*a*) consists of two parts: one is plate *1*, while the other *2* is E-shaped, with the projections slightly

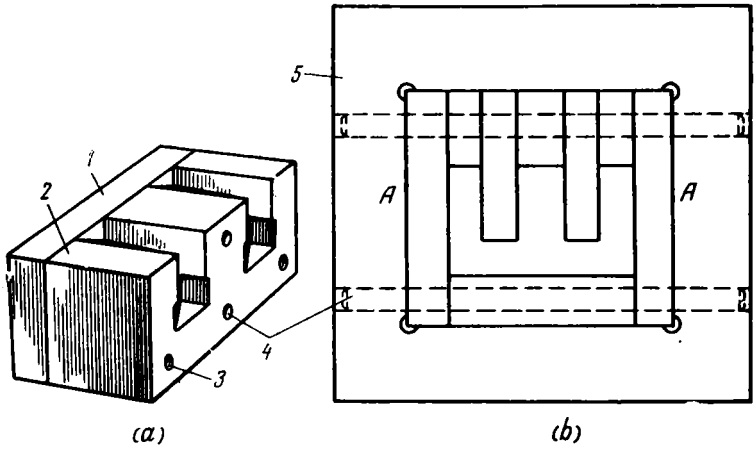


Fig. 100. Sectional punch and die for blanking E-shaped transformer laminations

(*a*) punch; (*b*) die; *1*—plate; *2*—E-shaped plate; *3*—hole for screw; *4*—hole for pin; *5*—case

undercut at their bases so as to facilitate the grinding of the walls. The two parts are fastened together by screws and locating pins.

The die (Fig. 100*b*) is made from several precision-ground plates joined by pins and enclosed in case *5*. For safer joining of the die plates, the pre-heated case is press-fitted over them. The interference is provided at two sides (*AA*) only, so as to force the plates tight over the mating planes. No tight fit is provided at the plate ends, since this may cause deformation of the middle plates and, thus, distortion of the die port.

To assemble the punch and die made in this way calls for minimum bench fitting, and their repair is very easy.

For large blanking and cutoff press tools, occasionally for moderate-size tools having an intricate cutting outline, the dies are made of step-shaped sections (Figs. 101*a*, *b*, and *c*). This saves labour required in making and repairing the tools and spares tool steel when the blunt sections must be resharpened.

Straight sections may be made from solid pieces (Fig. 101*a*), steel castings (Fig. 101*b*), or weldings

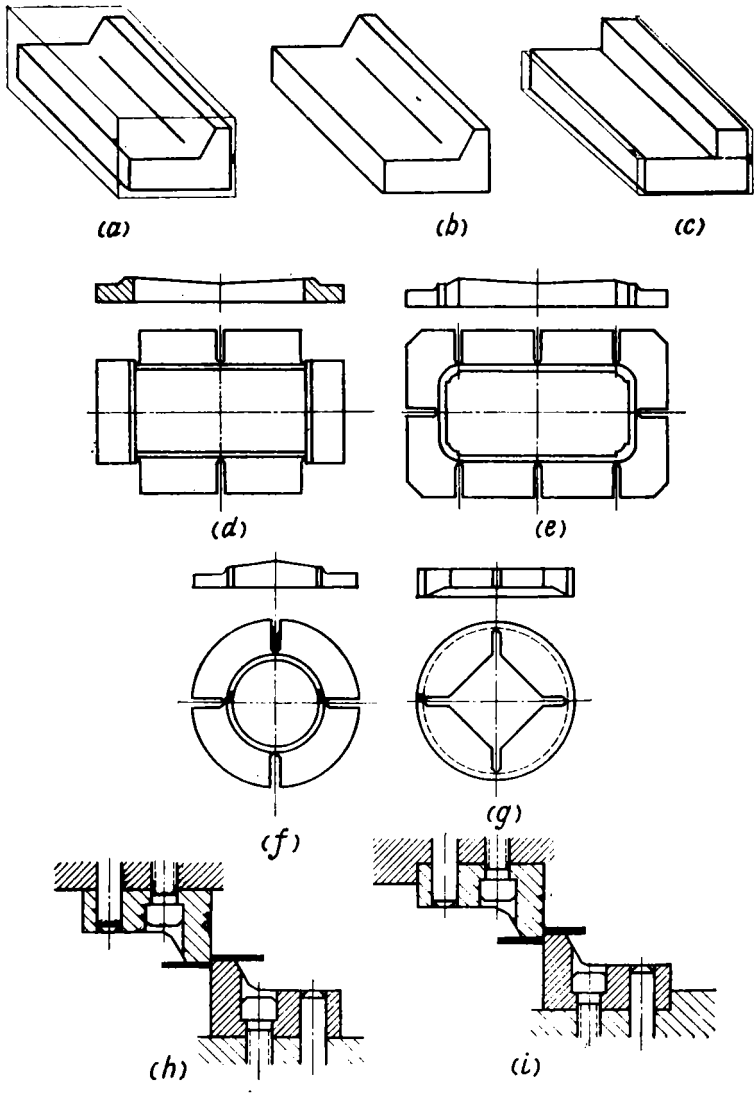


Fig. 101. Sections of dies and punches

(*a*), (*b*) and (*c*) blanks for step-shaped sections; (*d*), (*e*), (*f*), and (*g*) sectioning of dies; (*h*) attachment of sections to press tool shoes; (*i*) attachment to recessed shoes

(Fig. 101*c*). When making a press tool it is very important to correctly divide the cutting outline into separate sections.

The shape of sections must be simple so as to preclude their warpage in hardening and to offer convenience in machining, finishing, and assembling.

Protruding parts of the cutting outline should preferably make separate sections of a moderate size. The joints between the sections should be made on the straight parts of the outline at a distance of at least 5 millimetres from where a curvilinear outline changes into straight one. Figure 101 (*d*, *e*, *f*, and *g*) represents the examples of how to divide the cutting part of a press tool into sections.

The sections are screwed to the shoe of the press tool and locked by straight pins (Fig. 101*h*) that prevent the sections from shifting in assembly and operation. In heavily loaded press tools, the sections receive an additional support from a recess in the body of the shoe (Fig. 101*i*).

9.7. Machining of Punches

In normal practice, the manufacture of punches comprises essentially the following operations: cutting off a blank, rough machining, rough grinding, hardening, finish grinding the profile, finishing the profile, and sharpening.

Straight punches for blanking round contours or piercing round holes are easy to manufacture. They are turned on lathes, hardened, ground on circular or universal grinders, then their working surface is finished by polishing and the cutting face is sharpened (ground).

This is not so with shaped punches, far more difficult to make. The contour of a punch is first machined on metal-cutting machines keeping to marking for further machining; then an impression of the contour is made by the hardened and finished die; next, the punch is filed off according to the impression with due account to the required punch-to-die clearance; the punch is hardened and its working part is finished.

Depending on the stock thickness of the stamping in blanking and piercing operations, the punch-to-die clearance may be from 0.01 to 1 millimetre. When blanking 0.3-millimetre or thinner steel, the clearance per side is 0.01 mil-

limetre; in other words, the punch should be fitted to the die with practically no clearance.

Templets and measuring instruments cannot follow all the peculiar features of the die port shape accurately enough to be reproduced on the punch. This can be achieved only by making an impression of the die on the punch.

For obtaining an impression, an allowance of 0.2-0.5 millimetre per side is left on the punch when machining it. The allowance should be the greater, the more complicated is the outline. However, too large an allowance (for instance, 1 millimetre per side) makes it difficult to obtain a high-quality impression and may even spoil the die due to crushing of the cutting edges. On the other hand, an inadequately small allowance makes it difficult to obtain a good impression, because a high accuracy is required in mounting the punch with respect to the die port and the die working surface in order to obtain a uniform thickness of the stock to be removed from the punch over the entire periphery of the die.

Quite frequently an inaccurately made impression results in a nonuniform clearance. To eliminate this error, the punch edge is ground, milled, or filed to remove the stock to the depth of the first impression, and the impression is made again.

If this work is done carelessly or with little previous experience, the operation has to be performed several times since at the moment of impact (or under the action of a press) the punch may shift aside with respect to the shaped port in the die.

A good impression on the punch face may be obtained by using some of the elements of the die port itself. Thus, if the configuration of the shaped port in the die contains circular elements, the punch face can be provided with special mushroom bosses *1* (Fig. 102*a*). Such a boss is usually inserted in the hole for pilots in the punch. The diameter of the boss is equal to that of the die port. The punch is aligned with the die by means of the bosses and the impression is made by means of a press. This method ensures almost no shifting of the punch with respect to the die port and guarantees a uniform allowance for further machining over the entire periphery.

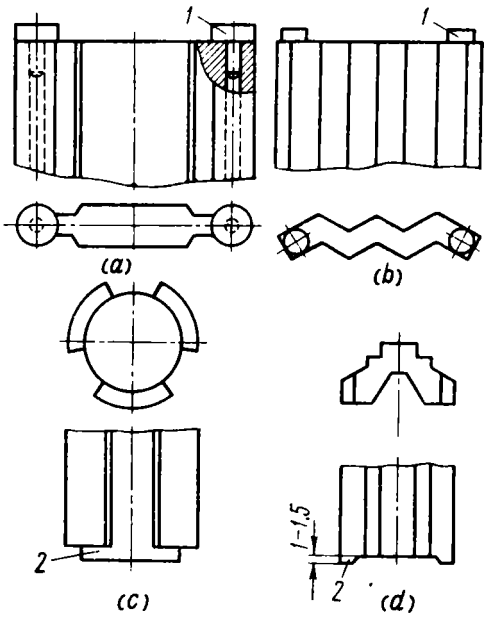


Fig. 102. Orienting punches to dies
(*a*) and (*b*) with mushroom bosses; (*c*) with a cylindrical boss; (*d*) with a shaped boss; *1*—mushroom bosses; *2*—boss

The guiding mushroom bosses may be used in some other blanking dies of intricate shapes (Fig. 102*b*).

If the punch outline includes some elements that can be obtained by turning (Fig. 102*c*), its face is provided with a cylindrical boss of a diameter corresponding to the shape of the die port. This boss is used for aligning the punch in the die. After the punch has been heat-treated, hardened, and finally fitted to the die, this boss is removed by face grinding.

In case of punches having no holes for mushroom bosses, a different method (Fig. 102*d*) is used. The entire surface of the punch face is milled down to a depth of 1-1.5 millimetres, except for only one or two sections which are the best, from the manufacturing point of view, for aligning the punch with the die. The resulting bosses are fitted to

the die and serve for correct mounting of the punch. Depending on the shape of the port in the die, these bosses may be left in different areas of the punch.

Punches with an impression of the die are planed over the entire periphery, leaving a minimum allowance for bench operations. Some shapes of the contour allow this operation to be done either partially or fully on a surface grinder with further bench filing to fit the die.

Punches of a simple shape (such as square, rectangular, cylindrical, hexagonal, etc.) need not be fitted to the die before heat treatment. After hardening, their contours are ground to the size of the shaped port in the die, observing the clearance prescribed in the drawing.

9.8. Profile Grinding of Punches and Dies

Profile grinding is grinding of surfaces different in shape and/or position from those parallel or perpendicular to the datum surfaces of the work.

Profile grinding may be performed on surface grinders using a shaped abrasive wheel or on jig-grinders and optical profile grinders. In most cases standard horizontal-spindle surface grinders are used for grinding the contours of sectional dies and punches of press tools, as well as those of mold inserts.

Machining profile parts on surface grinders is very efficient. The tool makers who know how to use properly surface grinders and their attachments and are skilful in shape trueing of abrasive wheels, will master new and efficient methods of machining intricate workpieces which have not been previously made by grinding.

All surface grinders are not equally suitable for profile grinding. The machines used for this purpose should be very precise and obedient to manual control of their table travel.

A surface grinder is equipped with an attachment for internal profile grinding, a magnetic plate having a rest bar, with indicating dogs limiting the travel of the wheelhead and table.

Special attachments are also required for accurate and systematic machining of straight and curvilinear profiles.

Grinding attachments may be classified into those for grinding straight elements, in parallel or at an angle to one another; grinding arched elements; spacing the elements of a profile along a circumference or a straight line; and those for combined grinding of elements.

Profiled surfaces can be ground with a grinding wheel of a standard shape or with a special profile wheel, i.e., a wheel shaped as required by a special device.

Let us consider, as an example, the machining of the profile of a punch for a blanking die used in pressworking (Fig. 103*a*). The heat-treated blank of the punch is mounted on the magnetic plate of a surface grinder and clamped in a vice or magnetic blocks. Figure 103 (*b*, *c*, *d*, and *e*) shows the sequence of grinding the profile of a punch.

The first to be ground are two flats (datum surfaces) necessary for positioning the punch in further machining. The punch is mounted on two magnetic blocks (Fig. 103*b*), the side surfaces of the tabs are ground to the size of $5.22_{-0.03}$ millimetres and the cylindrical surface D to the size of $14.2_{-0.03}$ millimetres.

In order to obtain a symmetrical arrangement of the side surfaces of the tabs and of the datum flats with respect to the punch axis, the punch is machined to the sizes of 14.2 and 5.22 millimetres in two operational stages, rough and finish ones.

Suppose that the measurements show the machining allowance in the tabs to be equal to 0.55 millimetre per side, and in the cylindrical part, 0.61 millimetre per side. In this case, a portion of the allowance, for instance, 0.5 millimetre, is first ground away from the surfaces A, B, C. In the course of this operation, an appropriate mark is made on the limb of the infeed handwheel of the grinding machine. Then the punch is turned over, mounting the surfaces A and B on the magnetic blocks, and the opposite surfaces of the tabs are ground to a depth corresponding to the mark on the handwheel limb. Thereafter the punch is measured. Suppose its sizes are 5.32 and 14.38 millimetres. Then the allowance for final machining is 0.05 millimetre per side in the tabs and 0.09 millimetre in the cylindrical part. This allowance is removed symmetrically by manipulating the handwheel against the limb.

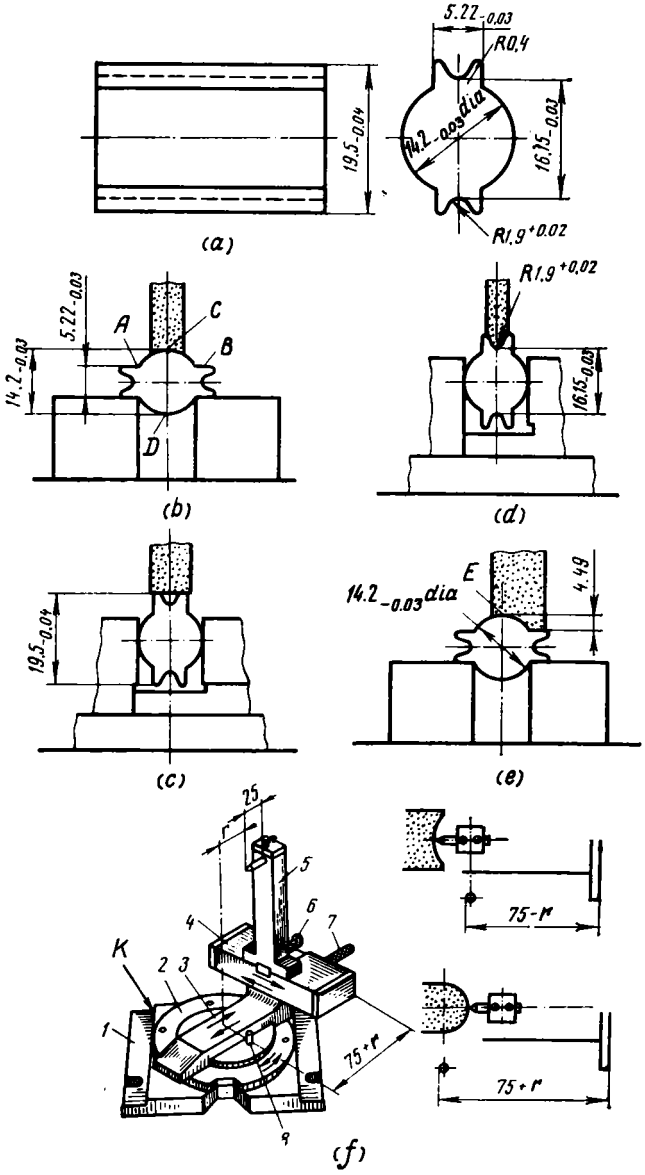


Fig. 103. Sequence of punch grinding and profile trueing of grinding wheels

(*a*) punch; (*b*) grinding the sides of the tabs and locating flats; (*c*) grinding the punch to the size of 19.5 millimetres; (*d*) grinding the cylindrical surfaces 19 millimetres in radius; (*e*) grinding the surfaces 14,2 millimetres in diameter with a profiled wheel; (*f*) universal attachment for profile trueing of a grinding wheel

Now the punch is fixed in a vice (Fig. 103*c*) to be ground to the size of $19.5_{-0.04}$ millimetres, feeding the wheel vertically and controlling its motion by the handwheel limb. Then the wheel is dressed to the arc 1.9 millimetres in radius and the valleys between the tabs are ground to the size of $16.15_{-0.03}$ millimetres (Fig. 103*d*). In this process, the punch is positioned over the surfaces *C* and *D*. To find this dimension, the slide gauge is set to a gauge block.

When trueing the wheel for grinding the punch surface $14.2_{-0.03}$ millimetres in diameter first the straight section of the generatrix is treated with a diamond, then the grinding wheel is gradually lowered by 4.49 millimetres with limb control (Fig. 103*e*) and the arc of a radius of 7.1 millimetres is made in the wheel. The grinding operation begins with touching the side of the tab with a grinding wheel (until slight sparking occurs), then the table is cross-fed for consecutive machining of all the four sections of the arc to the 7.1 millimetre radius.

The diameter ($14.2_{-0.03}$ millimetres) is measured with a micrometer.

To remove completely the allowance from the cylindrical surface of the punch, $14.2_{-0.03}$ millimetres in diameter, the grinding wheel trueing should provide a section (*E*) parallel to the straight section of the wheel generatrix.

The wheel may be profiled both by very simple devices, which allow trueing only over a straight or over an arc of a circle, and by universal devices, which serve for trueing the wheel to a complicated shape.

Figure 103*f* shows a universal attachment for diamond trueing of wheels, which allows a wheel to be shaped to a profile comprising different combinations of simple elements. Base *1* mounts swivelling part *2* whose slots serve as guides for tool rest *3*. Travelling over the top projection of the tool rest is shoe *4* with post *5* that carries a diamond trueing pencil. The central position of shoe *4* is locked by two pins *6*. With the pins retracted the shoe and the diamond pencil can freely travel both sides from the centre. The swivelling part can be secured in the required position or turned freely by means of handle *7*.

When adjusting the diamond for the prescribed profiling radius, the cutting edge of the diamond is set in the

initial position at a distance of 25 millimetres from the vertical post, this being done with the help of a special templet. If the tool rest is set so that the distance between pin *8* and the rear face of the tool rest is 75 millimetres, the cutting edge of the diamond tool will be set for the radius equal to 0, i.e., it will be on the axis of rotation of the swivelling part. If the tool rest is shifted forward to a size of $75-r$, the attachment will be set for profiling a concave arc section on the wheel, whereas the opposite shifting to a size of $75+r$ allows dressing to an arc of a convex shape.

In the process of setting and securing the swivelling part at a prescribed angle, the diamond can be shifted in the required direction with respect to the datum surface *K*, this being achieved with the aid of shoe *4*. The distance between the datum surface and the axis of swivelling must be accurately measured and marked on the attachment.

The marked size is constant for a given attachment, it underlies all calculations related to the adjustment of the attachment.

9.9. Manufacture of Punch Retainers, Strippers, and Heel Blocks

Strippers, heel blocks, and punch retainers are made after the dies and punches are ready.

The most difficult job is to make strippers for blanking press tools. The manufacture of strippers for blanking press tools is similar to the fabrication of dies. The shape and size of the working outline are obtained by the same methods as used in making dies. Similarly to the dies, the position and shape of ports in strippers are obtained by jig boring and slotting. An exception is made for holes for cylindrical piercing punches which are not bored, but drilled to suit the die.

After the strippers have been marked out and machined with fitting allowance, they are handed over to a fitter. The ports for trimming and piercing punches, that do not guide the profile punch with respect to the die port, but

merely strip the scrap off the punches, are usually machined to final size on machine-tools, since these ports normally have considerable clearances.

Punch retainers and heel blocks are processed to fit the punch. The process begins with the shaped ports. For this purpose the punch that is to blank the contour of the stamping is used to make an impression necessary for machining the port. The fitter, on receiving the punch retainer or heel block after machining, makes a new impression and uses it for finally filing the entire profile of the port, periodically using a try square to verify the direction of the port walls with respect to the surface of the work. No deviation from the vertical can be tolerated in ports for the punch, since an inclined punch will damage the die during operation.

This is why the best filing results will be achieved when the ports in a punch retainer or a heel block are handled on filing machines, setting the table at an angle of 90° with respect to the file plane. In manufacture of small-size press tools, the ports in punch retainers and heel blocks are made with the use of filing jigs.

It is often most convenient to machine a punch retainer together with the die. This processing method causes no difficulties when making a press tool with cylindrical holes in the punch retainer and the die. In such cases the punch retainer and the die are bored together. If the punch locating holes in the punch retainer and the ports in the die are irregularly shaped, they are filed together.

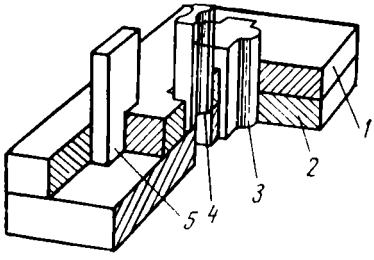


Fig. 104. Making the heel block of a press tool
1—die; *2*—heel block; *3*, *4*, *5*—punches

Punch *3* (Fig. 104) is introduced in the finish-shaped port of die *1* through heel block *2*. The two pieces are joined together with screw clamps and turned upside down. Then the other punch *4*, which pierces a shaped hole in the workpiece, is used to make an impression on heel block *2* through the die. To obtain

a clearer impression, the surface of the guide plate is tinned.

The same procedure is used for making an impression of the port for trimming punch *5*. The punch is inserted from the lower side of the die. These ports are then filed and finally punched through the die.

Most usually, shaped punches of an asymmetrical form cannot be inserted in the die from its bottom. This makes it necessary to resort to a different sequence when filing the ports in the heel blocks. If one punch is asymmetrical and all other punches are symmetrical, processing begins with the asymmetrically shaped port and then the remaining ports are filed to impressions.

When the die has several ports of asymmetrical configuration, identical ports in the heel block are fitted to the actual sizes of the die, i.e., the first port in the heel block is filed to suit the punch. Then this port is used as the base to locate the second and other ports by measuring the distance to, and position of, these ports on the die.

This task is notably facilitated by previously boring on a jig borer the basic elements of the shape of the ports on the heel block, to which the ports are later machined. When doing so, it must be taken into consideration that the die may be deformed during heat treatment and some of its sizes after final machining may deviate from those shown in the drawing. Therefore, when coordinating the heel block, one should make corrections according to the actual dimensions of the die.

To avoid damaging of the shaped ports in the die, do not file the ports in the punch retainers or heel blocks through the ports of the die.

When drilling the holes for cylindrical piercing punches, the punch retainer or heel block is assembled with the die, the shaped and trimming punches are inserted, screw clamps are tightened, and then the holes for round punches and locating pins are drilled and reamed through the die.

If the die has small narrow ports of different shapes, the piercing punches are made stepped to increase their strength.

The holes in the heel block are bored to the diameter of the thicker section of the punches. The die and the heel block (or the punch retainer) are assembled together, mounting all the straight-shank punches and locating pins. The form punch having the working section previously machined with an allowance is inserted into the hole in the heel block, and an impression of the shaped port in the die is made on the punch face. After filing to the impression, the punch is finally fitted to the die.

The fitting of the ports in the punch retainer is considered good if the punches are mounted according to the light drive fit and can be freely moved by hand in the ports of the heel block, but without any play.

One of the critical operations in the manufacturing of a punch retainer and assembling it with the punches provides a secure support for the punches. To achieve this, the bearing plane of the punch retainer is ground together with the punches press-fitted in it.

In the process of press-tool operation, a built-up edge is often formed on the punches. This is a layer of particles of the stamped metal adhering to the face of the punch at the moment when it passes through the hole being pierced or the work being blanked out. The building-up of the metal can be eliminated by polishing the working part of the punch; in non-critical cases, the working part of punches may be coated with blue vitriol.

9.10. Lapping and Polishing of Press-Tool Components

Lapping and polishing are final operations performed upon press-tool components. These operations are most frequently used in making press tools for drawing and extrusion.

Lapping is mainly applied to hardened components.

Lapping essentially treats the surface of a work with soft or hard abrasives. When using hard abrasives (powders), fine grains are placed between the surface to be treated and the lap which is usually softer than the work. The fine abrasive grains are harder than the surfaces between which they are placed, so under a certain pressure they are

embedded into the lap. Thus the surface of the lap gets filled up with the abrasive grains. The operation of forcing abrasive grains into the surface of the lap is referred to as *charging*. When the charged lap surface is moved over the work, the abrasive grains on the lap will cut particles of metal from the work surface.

Lapping with the aid of soft abrasives (pastes) differs from the above method and is used only for fine finishing of the work surface. The essence of this operation is in the formation of a fine layer of soft material on the work surface, resulting from a chemical reaction with chemical components introduced in the paste together with the abrasive material. As the lap moves, the soft abrasive removes the film from the protruding spots of the work. The spots that thus open are again treated by the paste and, thereby, coated with the film again and the process is repeated. In this way the metal surface is subjected to chemico-mechanical treatment.

Shaped cavities of hardened press tools (drawing, coining, and cold extrusion) are lapped with diamond points (see Section 1.5) or with laps of red copper, fibre, or textolite coated with diamond paste. For better adherence of the abrasives to the lap the surface of the latter is slightly roughened with an ordinary or needle file.

Figure 105*a* shows different shapes of lapping and polishing points to be mounted in the chucks of flexible-shaft machines.

Flexible-shaft grinding machines can be used for lapping the surfaces of punches and dies right at the fitter's workplace (Fig. 105, *b* and *c*), while spherical cavities in dies are lapped in the revolving chuck of a lathe (Fig. 105*d*).

The contours of profile ports in blanking dies are lapped on vertical lapping machines with reciprocatory motion of the tool (see Section 2.8, Fig. 17).

The efficiency of lapping largely depends on the speed of the lap motion. Higher speed means higher efficiency, but too high a speed leads to spilling of abrasive paste or lubricant and to heating of the work.

Higher accuracy of the work surface calls for lower speeds of lapping.

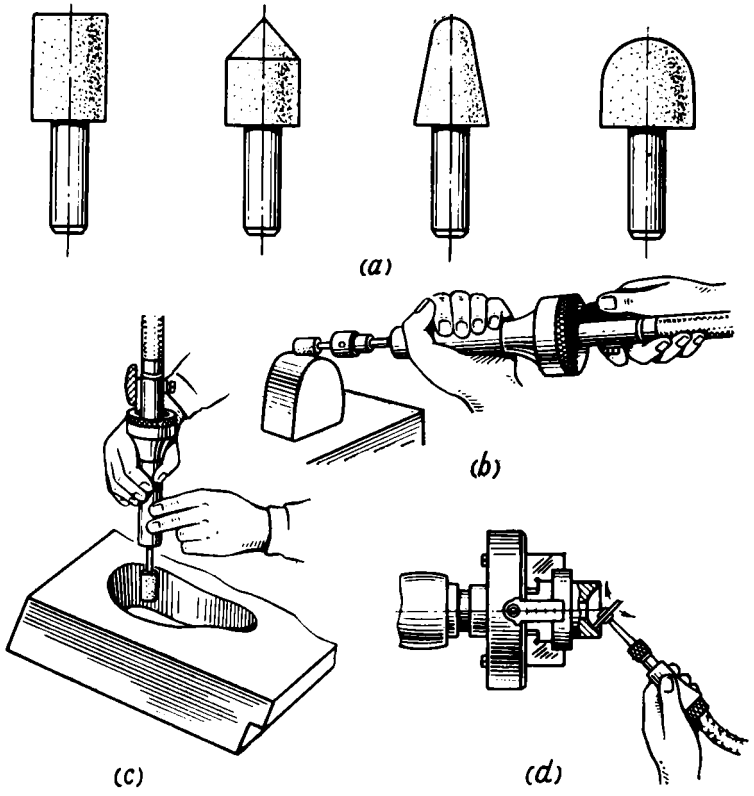


Fig. 105. Lapping and polishing points (*a*) and methods used for finishing shaped surfaces with powered hand tools (*b*, *c*, *d*)

Flat external surfaces of punches are lapped on a standard lapping plate.

For obtaining an accurate outline, blanking punches are lapped on cast-iron laps profiled to the outline of the punch.

The profiled laps allow a higher efficiency of lapping owing to simultaneous handling of the punch grooves, which produces strictly rectilinear and parallel grooves accurately located in one common plane.

The quality and efficiency of lapping depend on the lapping material, hence the latter must be carefully select-

ed to save time and avoid damage of laps and rejection of workpieces.

The grain size of abrasives is a major factor influencing the efficiency and quality of lapping. This is why the lapping operator should gradually change from large-grain (rough) to small-grain (fine) abrasives.

Never use contaminated lapping materials, do not mix up powders or pastes of different grain size. A thickened paste must be diluted with petrol, kerosene, or turpentine before application.

Polishing and buffing are aimed at improving the finish of the shaping surfaces of press-tool components, removing all traces left after the previous operations (notches, scratches, fine irregularities).

Polishing is used to remove mechanically all surface irregularities by loose abrasives or by grains bonded to the working surfaces of polishing buffs. Buffing is performed by loose grinding powders of fine grain size or soft elastic buffs coated with fine polishing pastes.

If the previous machining has been done well enough and no scratches, notches, or stretches are left, the stock removed by buffing is as thin as 0.03-0.05 millimetre. However, if polishing was preceded by treating the work with an emery cloth or a felt buff impregnated with coarse abrasive grains (grain size 80 or coarser), then a polishing operation may be called upon for removing as much as 0.1 millimetre.

In final buffing, termed colouring, the stock removed from the work surface is measured in microns or even fractions of microns. In the manufacture of press tools and moulds, the finish of polished surfaces can be as good as Class 12. The roughness which can be taken as a start for polishing should not be worse than Class 8. For colouring, the starting figure is Class 9.

To obtain the required class of surface finish, the grain sizes indicated in Table 9 may be recommended.

Good surface finish is obtained in several stages of operation, using ever finer grits in each subsequent stage. Each stage allows an improvement in the surface finish by one or two classes. The surface adequately prepared for polishing and having a high class of surface finish requires

Table 9

Surface Finish vs. Abrasive Grain Size

Class of surface finish	Grain size, microns
7-8 (finish grinding)	40-28
9 (polishing)	28-20
10 (buffing)	14-10
11-12 (colouring)	7-5

fewer stages of finishing, its treatment is more efficient, with spare use of abrasive materials.

In tooling manufacture, polishing must meet special requirements. A major requirement consists in obtaining the required surface finish without distorting the size and shape of the work. No defects may be tolerated on a polished surface.

If deep notches, scratches, blisters, or dents are detected on the surface to be polished, they must be first removed by grinding with an abrasive wheel or emery cloth; only after this has been done, polishing may be commenced. Polishing is usually begun with the areas where faults are most likely.

Polished surfaces should have no burnt spots of a blue-brown colour (discolouration) due to local overheating of the metal surface layers. Chromium-plated surfaces after polishing should have no notches, blisters, dents, yellow spots, spots with stripped-off coating, cracks, incompletely-polished areas, or areas ground down to the basic metal or to the underlayer of copper.

There also exists a polishing technique which consists in preparing the work surface for electroplating and is known as *dull finishing*. The polishing buff of felt or cloth is periodically coated with pastes containing fine abrasive grains (synthetic aluminium oxide or other type). The most efficient for this purpose are silica flour pastes, since their grains leave no deep scratches on the surface.

Dull finishing is performed with the wheel rotating across the previously-obtained lay direction. This results in a considerable decrease of surface roughness and in a

better adhesion of the electroplated layer. Besides, polishing of a layer plated over a dull-finished surface proves more efficient, and a thinner layer of chrome has to be removed.

Polishing may be done on lathes, grinders, or drilling machines. The rotation can be imparted either to the polishing buff or to the work, which depends upon the shape of the surface to be polished, as well as upon the shape and weight of the workpiece.

Polishing may also be performed with the aid of pneumatically or electrically driven hand tools with polishing points of the required shape installed in the chuck.

To gradually feed the abrasive mass to the working surface of a polishing power tool, its centre is provided with a through hole or a taper bore filled with the abrasive mass prior to operation. During the tool operation, the polishing mass gets under the buff and then to its working surface, thus replenishing the used or spilled mass.

The pastes usually consist of machine oil, kerosene, paraffin or stearin, and a very fine abrasive powder, all taken in the required proportion.

For manual polishing of steel surfaces, the most common lubricant is kerosene which serves for diluting the abrasive powder or paste.

The shaping cavities of press tools are buffed with fine-felt or leather buffs coated with an abrasive paste. The felt buffs are rotated at a speed up to 8000 rpm.

The rough-felt buffs are used for polishing at low speeds, since high speeds rapidly wear them out.

Colouring is performed with hard (copper, fibre, or wooden) points coated with a thin layer of polishing paste containing chromium oxide, iron oxide (crocus), or tripoli.

Good polishing largely depends upon the correct selection of the peripheral speed of the buff. When polishing steel or chrome workpieces by buffs with abrasive powders, the speed is 20-35 metres per second, while buffs with pastes must run at a speed of 30-50 metres per second. Intricately-shaped surfaces are polished at lower peripheral speeds.

The pressure exerted by the buff upon the work should be within 25-50 newtons. Polishing is performed at a greater pressure, buffing, at a weaker pressure. In colouring,

the pressure should be very slight, otherwise spots and discolouration may occur.

9.11. Press-Tools Assembly

Methods of assembly. Assembly is the final and most important process in the manufacture of press tools. Even a slight inaccuracy in assembly may lead to shorter life of the press tool or cause an accident.

The assembling procedure includes the following jobs:

(1) collecting a complete set of components for the press tool and checking their quality;

(2) performing fitting and machining operations to prepare the components for assembly (chamfering; drilling, countersinking, and threading holes for screws; drilling and reaming holes for locating pins, etc.);

(3) assembling the die with the lower shoe;

(4) assembling the punches with the punch retainers;

(5) levelling and adjusting the bearing surface of the punch retainers and the cutting surfaces of the punches;

(6) assembling the upper and lower shoes on the guide posts;

(7) installing and securing the punch retainers and punches on the upper shoe;

(8) mounting the stippers and locators;

(9) finally assembling the press tool, testing the operation of its moving components, and checking the clearances between the working parts;

(10) trying out the press tool on a press, detecting faults, and remedying them;

(11) trial stamping the parts, marking the press tool, and handing over the finished press tool to inspection.

When assembling a press tool, special attention should be paid to the quality of machined components to be assembled, the conformity of their geometric shapes and sizes to the drawing.

Blanking press tools must meet the following requirements in assembly:

(a) conformity of the geometry and dimensions of the die ports and the punch outline to the drawing;

(b) straightness of vertical walls in the straight clea-

rance and widening downwards of the angular clearance;

(c) observance of the pitch distances between the contour ports, holes for piercing punches, and ports for trimming punches; ensuring the parallelism of their internal cutting sides;

(d) straightness of the punch stem with no flaring upwards;

(e) uniform clearances between the walls of the shaped ports and the surfaces of the punches after the latter have been mounted in the punch retainer;

(f) observance of the pitch distances in the dies of progressive tools and enlargement of the ports for trimming punches by 0.2-0.3 millimetre in press tools equipped with pilots;

(g) uniform upsetting of the heads of shaped and trimming punches (to avoid their skewing in the punch retainer);

(h) secure mounting of punches in the punch retainer due to tight fit in the ports rather than caulking;

(i) perpendicularity of punches to the plane of the punch retainer and their equal height;

(j) straightness of ports in the heel block and their correct mating with punches without a notable clearance;

(k) secure mounting of press-fitted guide posts and bushings in the shoes of the press tool and their correct mutual arrangement (by centre-to-centre distances);

(l) perpendicularity of posts and bushings to the support planes of the shoes and parallelism of the shoe planes.

After testing all the components for their correct manufacture, their assembly begins.

Mounting the stock guide rails is the first operation in the assembly of blanking, piercing and progressive dies. If the distance between the rails is too large, the strip will run loosely behind the trimming punches and the stamping will have unequal sides.

If the punches are provided with pilots, the distance between the guide rails may be 0.2-0.3 millimetre larger than that between the trimming punches.

For the guide rails to be mounted correctly on the die, one of them is secured by screw clamps on the die surface in such a position when the guiding surface of the rail is

flush with the internal surface of the trimming punch. This can be checked with a standard master straightedge.

The other guide rail is set to two gauge blocks of equal size, placed between the bars. The size of the gauge blocks is equal to the width of the strip plus the required clearance. After the two guide rails have been secured by screw clamps, holes for locating pins are drilled and reamed in them through the die.

Press-fitting of punches in the punch retainer is performed after the heel block has been mounted in place. An accurate alignment of the ports in the heel block with those in the die is achieved by inserting shaped and trimming punches through the heel block into the die (to a depth of 3-4 millimetres), which fixes the heel block in the correct position. The die and heel block are secured in this position by screw clamps, and holes for locating pins are drilled and reamed through the die; after the pins have been mounted, holes for fastening screws are drilled. Thereafter, the punches are mounted in the punch retainer.

This operation is normally performed in steps; the first to be mounted is the main (shaped) punch, that blanks out the part (Fig. 106*a*). Punch *2* is inserted in punch retainer *1* at a right angle to the plane of the punch retainer. Its perpendicularity is checked with try square *3* on four sides.

After the shaped punch has been installed, the next punch is inserted in the respective port of the punch retainer. Checking only with a square is not sufficient; the die must be imposed upon the punch retainer. Then an electric lamp is lit beneath to see whether there are uniform clearances over the entire contour of the die set on the punches.

It may happen that, after a correct installation of two or more punches in the punch retainer (i.e., when the vertical walls of the punches are perfectly at a right angle to the plane of the punch retainer), the position of all punches does not correspond to the position of the respective ports in the die and the latter will not set on the punches. Most usually this is due to an incorrectly made punch retainer, and erroneous location of holes in the punch retainer can be detected.

In such cases the position of the punch may not be corrected by caulking the hole at one side; though the working

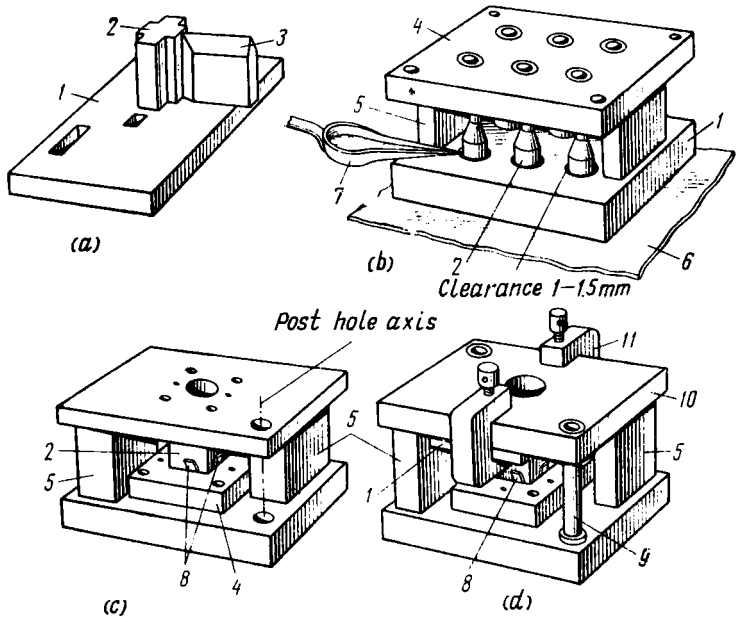


Fig. 106. Methods of press-tool assembly

(*a*) mounting the punch in the punch retainer; (*b*) bonding of punches with a fusible alloy; (c) and (*d*) methods of mounting the punch retainer; *1*—punch retainer; *2*—punch; *3*—try square; *4*—die; *5*—spacer; *6*—asbestos spacer; *7*—ladle; *8*—foil; *9*—post; *10*—upper shoe; *11*—screw clamp

face will thus be brought into alignment with the die port, the punch itself will remain inclined in the punch retainer and, consequently, will cut the die after it is resharpened several times.

The punches should be light-drive fit in the punch retainer. If the punches are freely set in the ports and then upset by caulking to eliminate play, they will get loose in operation and start cutting the die. This is especially bad for press tools with no heel blocks to guide the punches.

The more punches are there in the press tool, the more difficult is their installation. To facilitate this operation, press-fitting of punches in the retainer is replaced by their bonding with a fusible alloy or a quick-setting plastic.

When using this method of assembly, the locating surfaces for the punches are machined to obtain a clearance of 1.0-1.5 millimetres per side. Cross grooves are cut in the punches, and the surfaces contacting the alloy are etched and tinned. Then the punches are set in the position shown in Fig. 106*b*. Punch retainer *1* with punches *2* is mounted on a cast-iron plate, and die *4* is mounted atop on spacers *5*. To install the punches in the die ports with the required clearance, use is made of pieces of foil. With very small clearances, the die ports are made to push fit over the punches; when the assembly is over, the die ports are enlarged to the required size which ensures the proper clearance. An alternative method is to make centring belts on the punches at a distance from their cutting parts, the belts being pushed fit in the die ports. The assembly is fastened with screw clamps, heated up in an electric furnace or hot sand to a temperature of 100-110°C and installed on a cast-iron plate covered with asbestos spacer *6*. Then the clearances between the sockets of the punch retainer and the punches are filled from ladle *7* with a molten alloy consisting of 48 weight per cent bismuth, 28.5 per cent lead, 14.5 per cent tin, and 9 per cent antimony. The melting point of this alloy is about 120°C. After the alloy has hardened, its beads and splashes are scraped away, and the die is applied to verify whether the punches are correctly mounted in the retainer.

Mounting the punch retainers in assembly with the punches can be done in different ways. One of them is as follows: first, the die is assembled with the lower shoe, and the punch retainer with the punches is assembled with the upper shoe. Then the top and bottom parts of the press tool are joined so that the space between punch *2* (Fig. 106*c*) and die *4* is large enough to accommodate sheets of foil *8* as thick as the clearance. This done, the top of the tool is lowered onto two parallel spacers *5*. Now the set is ready for boring all the holes for guide posts and bushings with one setup.

Another method (Fig. 106*d*) consists in assembling first the set of the press tool (i.e., the die is joined to the lower shoe and secured with pins), then, using foil sheets *8*, the punch in assembly with the punch retainer is introduced

in the die hole observing the prescribed clearance. Then upper shoe *10* is lowered over posts *9* till it contacts the bearing surface of punch retainer *1* and is placed upon parallel spacers. The punch retainer is fixed in this position to upper shoe *10* by screw clamps *11*, and the two components are drilled and reamed to make holes for pins. When the pins have been set, the punch retainer and the upper shoe are drilled again, now to make holes for fastening screws. All this ensures a correct assembly of the die.

To see whether the punches have been correctly installed in the punch retainer, a trial blanking cut is done on paper or cardboard of a thickness equal to that of the metal to be stamped. For this purpose, the following procedure is pursued. The heel block is placed upon the die using the locating pins, then the punches mounted in the punch retainer are introduced in the heel block. A paper or cardboard strip is drawn between the stock guide rails, pressure is exerted upon the upper shoe carrying the punch retainer, and the punches are introduced into the die. The paper strip is removed by lifting with the aid of levers the punch retainer, and the accuracy of the cut contours is examined. If the punch-to-die clearances are correct, the cut will be accurate. If the clearances are nonuniform, the contour of the cut will be torn or the paper will be drawn into the punch-to-die clearance where the clearance is the largest.

Press tools with ball-bearing guide posts are assembled on a bench, turning the tool as in Fig. 107*a*.

The press tool with the separators set on the posts is located on the edges of the shoes, aligning the faces of the posts and bushings at one level. Then the distance l between the planes of the die and the punch is measured. The separators are placed in the bushings of the top and bottom shoes in the way shown in Fig. 107*a*, and the top and bottom parts of the press tool are brought together.

Figure 107 (*b* and *c*) describes the correct and wrong positions of the separators in the bushings of the upper and lower shoes with the press tool open and closed.

If the interference between the balls, the post, and the bushing is inadequate, the separators may slip down in operation. This can be prevented by placing springs under the slipping separators (Fig. 107*d*).

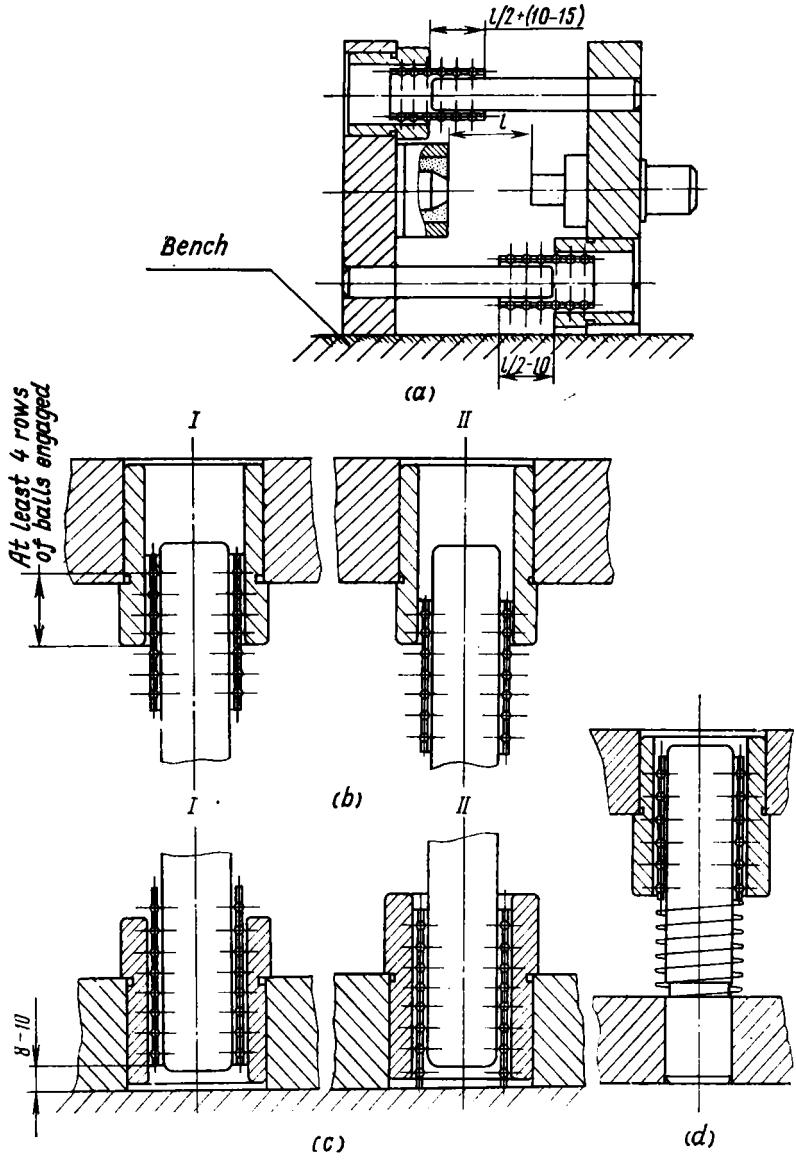


Fig. 107. Mounting ball-bearing separators

(*a*) in assembling the tool; (*b*) position of the separators in the bushings of the upper shoe with the tool open (*I*—correct, *II*—wrong); (*c*) position of the separators in the bushings of the lower shoe with the tool closed; (*d*) spring loading a separator

Mounting a press tool in a die set. When a press tool is mounted in a die set, the assembly proceeds in the following sequence. First the bottom part of the tool—die *2* (Fig. 108) and stripper *3*—is placed in the centre of lower shoe *1* of the set and joined together by screw clamps. Then, inserting the drill through the die, holes for screws are drilled in the lower shoe of the set. After drilling these holes and screwing the die to the lower shoe, the drill is again inserted through the die to drill and ream holes for locating pins, and the pins are installed in place.

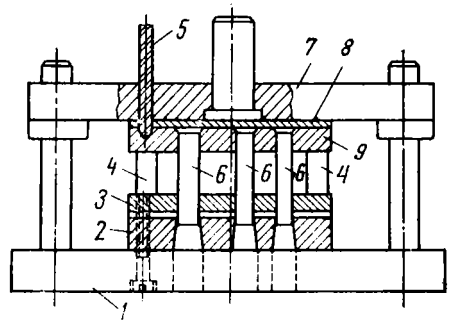


Fig. 108. Mounting a press tool in a die set

1—lower shoe; *2*—die; *3*—stripper; *4*—spacers; *5*—drill; *6*—punches; *7*—upper shoe; *8*—punch backup plate; *9*—punch retainer

Prior to securing the top part of the tool, punches *6* installed in punch retainer *9*, are introduced in the ports of die *2* to a depth of 1.5-2.0 millimetres. To avoid misalignment, two parallel spacers of equal height are provided between stripper *3* and punch retainer *9*. When the tool is thus pre-assembled, upper shoe *7* is lowered on it.

Two methods are known for securing the top part of the tool to the upper shoe of the set. The first consists in securing the punch retainer to the shoe by means of two screw clamps, removing it from the posts, drilling and reaming holes for the locating pins in the plate of the set, and inserting drill through the punch retainer. After the pins ar mounted, the holes for screws are drilled. A limitation c this method is that the punch retainer may shift, if it is insufficiently tightened with the screw clamps, and thus distort the correct mating with the die.

According to the other method, the punch retainer is secured to the shoe by screw clamps, and the holes for locating pins are drilled and reamed without disassembling the press

tool, but using the layout with drill *5* introduced through the upper shoe of the die set.

The holes for screws are drilled through the punch retainer after the locating pins have been mounted and the press tool disassembled. A limitation of this method is that punch backup plate *8* can be heat-treated only after all the holes have been drilled; this extends the time of assembly.

The proper installation of punches, stops, stock guide rails, etc. is tested with paper or cardboard strips of a thickness equal to that of the material to be stamped.

9.12. Assembly of Press Tools with the Use of Quick-Setting Plastics

Quick-setting plastics are gaining an ever wider application in the manufacture of press tools and their components. Most simple to prepare and convenient to use are plastic compounds based on acrylic resins, known as acrylic plastics. These materials set at room temperature under a pressure of 1-3 megapascals or no pressure at all.

The wastes of acrylic plastics can be fully reused.

Application of acrylic plastics in the fabrication of blanking press tools obviates the need of accurate marking of holes in heel blocks, punch retainers, strippers, and knockouts, alignment of these holes for machining and manual fitting. These materials are especially efficient in making multi-punch tools.

Consider the assembly of a blanking press tool, using quick-setting plastics.

The press tool shown in Fig. 109 is intended for blanking a part and piercing a hole in it. The design of this tool uses plastics for facing the knockout and stripper, as well as for securing the blanking punch and guide-post bushings in the shoes. Knockout *1* and stripper *3* (each) comprise two parts, a metal body and plastic facing *6*. The bodies of the knockout and the stripper are made with grooves 5-8 millimetres deep intended to keep plastics. The hole in the stripper body is made 5-8 millimetres larger than the part, and the knockout is 5-8 millimetres smaller than the part outline.

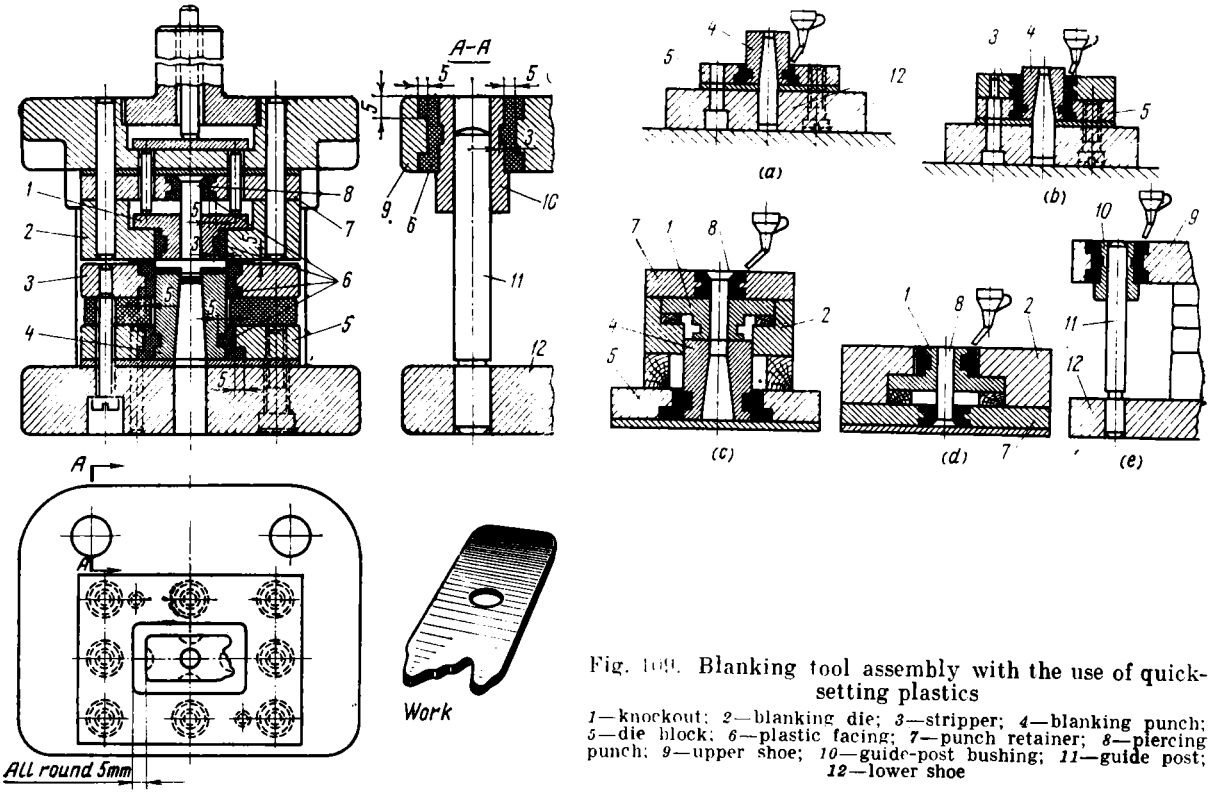


Fig. 169. Blanking tool assembly with the use of quick-setting plastics

1—knockout; *2*—blanking die; *3*—stripper; *4*—blanking punch; *5*—die block; *6*—plastic facing; *7*—punch retainer; *8*—piercing punch; *9*—upper shoe; *10*—guide-post bushing; *11*—guide post; *12*—lower shoe

The knockout is faced in finished blanking die *2*, made of metal, and the stripper, in finished blanking punch *4*, also made of metal. The die is previously coated with a parting compound. For filling the cavity between the stripper body and the blanking punch, as well as for filling the cavity between the knockout body and the blanking die, use is made of a plastic with a high resistance to abrasion.

Piercing punch *8* is secured in punch retainer *7*, blanking punch *4* is secured in die block *5*, and bushings *10* for guide posts *11* are secured in the shoes due to adhesion of the materials and owing to the grooves made specially for the purpose. The cavity between the components to be joined is filled up with plastics.

When assembling the press tool, lower shoe *12* is mounted dead horizontally on a surface plate, and a backup plate for die block *5* is placed upon it. The backup plate must be previously coated with a parting compound. Now the die block is placed on the backup plate and screwed to it, then blanking punch *4* is put in place and locked by a pin inserted through the respective hole in the lower shoe.

The resin is poured into the cavity between the die block and the blanking punch (Fig. 109*a*) and held for 12 hours for setting. When the plastics sets, it is treated with fitter's tools. Then the blanking punch and the die block are coated with the parting compound. Stripper *3* is installed in the lowermost position and fixed so with screws. The cavity between the blanking punch and the stripper is filled with the resin (Fig. 109*b*) left for setting for 12 hours and then treated with fitter's tools.

The faced stripper *3* is removed from die block *5*. Blanking die *2* and the body of knockout *1* are coated with the parting compound. The die is mounted on the die block and, in turn, receives the knockout body and piercing punch *8* with punch retainer *7* prepared for resin filling-in. The cavity between the punch and the punch retainer is filled up with the resin (Fig. 109*c*) which is held for 12 hours for setting.

The set plastics is treated with fitter's tools, then the punch retainer with the piercing and the blanking die are coated with the parting agent and placed on a surface plate. Introduced in the die is the body of knockout *1* ready to be

faced (Fig. 109*d*). The cavity is filled up with the resin which is held for 12 hours and then treated with fitter's tools. Thereafter guide posts *11* are press-fitted in lower shoe *12*, the press tool is closed; the cavity between the guide-post bushing and its hole in the upper shoe (Fig. 109*e*) is filled up with the resin held for 12 hours and treated with fitter's tools. All this done, the press tool is assembled, fastened with bolts and pins, the rubber pad and pushers are mounted, the assembled tool is tested and adjusted.

9.13. Inspection and Adjustment of Press Tools

General. Assembled press tools are inspected and checked up to see whether their dimensions and shapes are in full conformity with the specifications.

When inspecting bending, drawing, and extruding tools, it is necessary to see whether the elements of their profile and relief are properly mated, the top and bottom parts of the tool are properly aligned, and the mating components and units interact duly.

The most reliable method of comprehensively testing the press-tool quality consists in employing the tool under real production conditions, i.e., mounting it in the press and performing trial stamping operations.

The tests are carried out using the equipment and blanks available in the stamping shop and specially reserved for testing and adjusting the press tools. During the trials, all the rules for operating the press tools should be strictly adhered to.

The following rules are to be observed when mounting the tool in the press:

(1) never mount the tool in a press which is not suitable for testing this particular type of tool;

(2) prior to mounting the tool, make sure that the press is in good working order and has the necessary safety guards and accessories, its safety devices are in order, and the clearances in the slide guides are properly adjusted;

(3) see that there are no foreign objects or tools on the bolster plate when the tool is mounted in the press; wipe clean the bearing surfaces of the tool and of the bolster;

(4) always use mechanical handling devices to mount heavy press tools (Fig. 110);

(5) when mounting a press tool operated with the use of a pneumatic cushion, see that the holes in the bolster are

Fig. 110. Hand-operated hydraulic hoist for handling press tools and mounting them in presses

not clogged with slugs and waste, and that there are no slugs on the surface of the cushion proper; also, check up the length of the transmission rods;

(6) do not mount the press tool in the press unless the distance between the press slide (the slide down and stroke adjustment up) and the bed exceeds the shut height of the die;

(7) when mounting the blanking, trimming, and piercing tools, adjust the slide so that the punch penetrates into the

die to a depth equal to the thickness of the material being stamped;

(8) when mounting the bending and forming press tools intended to stamp metal up to 2 millimetres thick, adjust the press pitman so that the punch just contacts the die; if the stock is thicker than 2 millimetres, arrange strips of the stock before adjusting the pitman;

(9) for safer work and prolonging the life of the tool, secure the tool in the press reliably, using special plates, cramps, bolts, and washers, but avoiding channel pieces of metal used as plates or spacers.

In presses which have served for a long time, the plane of the bed may get inclined to the bearing plane of the press slide (i.e., the bed plane is not perpendicular to the slide axis). Use a try square and a dial indicator secured on a post to verify the position of the bed and take into account the deviations when mounting the press tool.

After the press and its mechanisms have been inspected and the bed wiped clean, set the slide for the required stroke and adjust the shut height as necessary for the operation; then proceed with mounting the press tool.

If the stampings are to drop through the bed port, see whether the bed port corresponds to the size of the stamping. If the stampings are not expected to drop, the tool is mounted on ground spacers so that the stampings could be withdrawn from beneath the die shoe. The spacers should be placed as near the ports in the shoe as possible so as to minimize bending stresses in the shoe and allow the stampings to freely drop through.

Mounting and adjusting small and moderate-size press tools. Press tools intended for work in presses of a tonnage of less than 100 tons usually have a shank by means of which the top part of the tool is joined to the press slide. In tools with heavier upper shoe this method of attachment proves unreliable, and the shoe is secured additionally by bolts through holes in the slide and tool (Fig. 111*a-e*). The bottom part of the tool can be attached to the bolster by either of the two following methods: by straps or cramps bolted to the flanges of the bolster (Fig. 111*f* and *g*) or by bolts through slots in the flanges of the lower shoe (Fig. 111*h*). The latter method is more reliable.

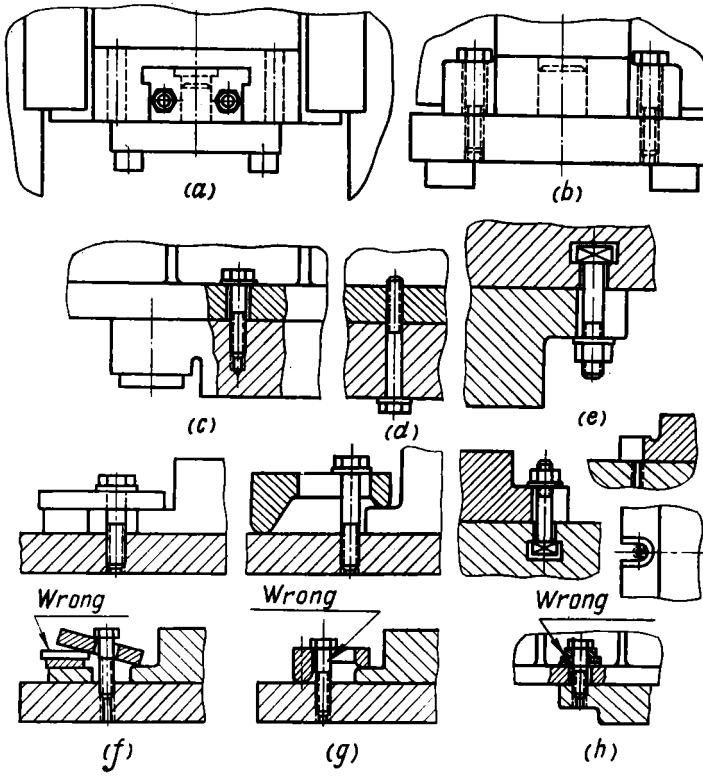


Fig. 111. Attaching press tools in presses

After placing the closed press tool on the press bed so that the shank is in the slide socket, the slide descends in its lower position and the top part of the tool is tacked to the slide. Then the screw of the pitman is turned to lower the slide till it fully contacts the surface of the upper shoe and the shank is finally fastened by the clamp, bolts, and nuts.

Thereafter, the slide is made to go slowly up and down to verify the alignment of the press tool and to eliminate misalignment and skewing.

To attach the lower shoe, the bolts with plates, washers,

and nuts on them are inserted in the slots of the press bed and brought close to the press tool, then the plates are placed on the lower shoe and the nuts are tightened uniformly so as to avoid skewing of the die.

If the attachment is correct, the bolt plate will be parallel to the press bed, resting against the die shoe with one end, and against a pad with the other. When attaching the press tool, avoid using improvised straps or nuts. Figure 111(*f* to *h*) shows incorrect methods of attachment which may cause a failure of the tool and render the press inoperative.

For final attachment of the tool, use a feeler gauge for testing how tight the bearing surface of the lower shoe lies against the face of the press bed over its entire perimeter. Should any gaps be detected, the tool must be placed on pads and tested in motion for correct alignment.

After the top and bottom parts of the tool are finally secured in their places, the height of the press slide is adjusted by a screw and stopped by a bolt or slide blocks where required.

Test press tools with guide posts by making several idle strokes of the press with the tool mounted in the press. If the guide posts operate incorrectly (for instance, the posts rub against the bushing walls), loosen the fasteners of the tool bottom, give the press two or three idle strokes, and then tighten the fastening bolts again with the slide in the lowermost position.

The bolts should be tightened gradually, step by step.

When adjusting a blanking tool in which the part blanked out remains in the top of the tool, adjust the power-operated knockout arranged in the slide. Such knockouts are provided in gap-frame presses of a tonnage of up to 100 tons.

Figure 112(*a* and *b*) describes the connection between the press tool and the knockout. A hole drilled in the tool shank receives rod *1* resting against push plate *2* with one end and against the workpiece with the other. During the blanking operation the workpiece gets into the port of the die and elevates the rod and the push plate. As the slide approaches its uppermost position, the push plate runs against adjustable stops *3* and pushes down the rod which knocks the workpiece out of the die.

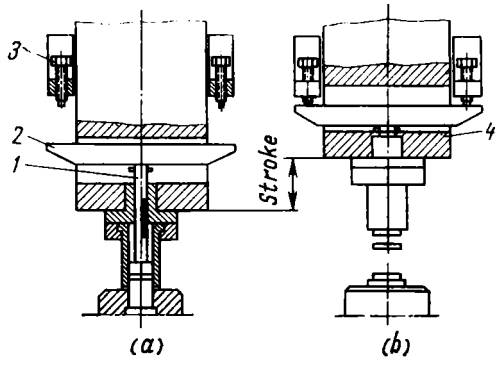


Fig. 112. Connection between press tool and knockout in different slide positions
(*a*) slide in the lower position; (*b*) slide in the upper position; *1*—rod; *2*—push plate; *3*—adjustable stops; *4*—press slide

Stops *3* should be so adjusted as to prevent the push plate from bearing against slide *4* by the end of knocking-out, but make it stay on rod *1*. An encounter of the slide and the push plate may cause an accident, since stops *3* are connected with the press frame. With the slide in the uppermost position, adjust the stops for the workpiece to be knocked out at this position.

For adjusting the slide stroke on a gap-frame crank press, the left-threaded nut (see Fig. 61) is unscrewed, and the lock clutch is pulled aside so as to disengage it from the eccentric bushing. Then the slide can be set for the required stroke by turning the eccentric bushing.

To make the adjustment easier, the journals of many presses have divisions showing the respective stroke.

After the slide stroke has been set, the lock clutch and the bushing are brought into engagement again and the stroke is tested with the press running.

The slide-stroke adjuster of straight-side presses is arranged in the middle of the crankshaft, near the pitman, and is essentially similar in design to that employed in the

gap-frame presses. In many straight-side presses the slide stroke cannot be adjusted.

Modern presses capable of up to 100 tons are provided with electro-pneumatic controls which make the adjustment easier; in presses with air-actuated friction clutches, the adjustment is carried out at jerk strokes of the slide, obtained by pressing the electric push button.

On a quick-acting press delivering over 90 strokes per minute, the slow lowering of the slide can be achieved by first switching off the electric motor, and then pressing periodically the push button "Brief operation".

In closed blanking tools, the punch in its lower position should penetrate into the die opening to a depth not less than 0.7 and not more than 1.5 the stock thickness.

In presses with a positive clutch for engagement through a key or a pin, the slide is brought down by manually turning the crankshaft till the slide contacts the punch plate. For reliable adjustment of the punch elevation over the die, two measuring blocks are placed between the top and bottom of the press tool. When securing the tool, it is necessary to guard against misalignment which may lead to an accident.

To provide a uniform clearance between the punch and die in press tools having blankholders, the blankholding devices should be tightened up with screw clamps so that the punch projects from it by 6-8 millimetres. Then pieces of foil are used to mount the punch with a uniform clearance with respect to the die.

Having eliminated any misalignment of the top and bottom parts of the press tool, check the punch-to-die clearance by trial stamping of soft-metal parts (to avoid the risk of damaging the working parts of the tool).

If burrs arise on one side of the part, close the press tool and loosen the fastening of its lower shoe, then tap lightly against the shoe to move it to the side opposite to where the burrs occur.

When mounting a press tool with a heel block, adjust the slide stroke so as to keep the punch always in the heel-block port.

When a press tool with guide posts is mounted in the press, the bushings and posts should be lubricated. See also

that the posts, jutting over the upper shoe of the closed tool, do not contact the slide.

The procedure of mounting open blanking and piercing tools is similar to that employed for closed ones.

Bending tools are mounted with their top and bottom parts closed together. A test sample of the stamping is placed between the punch and die, the sample being 1.1-1.15 times as thick as the actual part to be made.

When bending is to be performed in a blind die or in a die with a blankholder, crank the shaft several times by hand to make sure that the slide passes the lower point freely, without jamming. If the bending operation is carried out in tools with a spring knockout, adjust the spring or rubber cushion so as to knock the part out of the die.

After having made sure that the slide runs freely, the bottom part of the tool is finally secured by clamps and trial bending is performed on several parts which are then inspected by checking their dimensions and appearance and comparing to gauges.

Adjustment of sizing press tools requires special care, since wrong adjustment of the shut height may lead to press breakdown or a thrust, i.e., overload of the press, bringing all its moving parts to an abrupt stop and jamming the press tool. If, when eliminating a thrust, the slide cannot be moved up by manual or power controls, a press setter-up should be sent for.

Mounting small-size drawing tools differs from the procedure used for bending tools in that the bottom of the tool is attached to the bolster in such a position when the punch with a test stamping on it is lowered into the die port. The walls of the test stamping is usually 1.2-1.4 times as thick as those of an actual part drawn without wall thinning.

The press stroke is adjusted to be 2.5-3 times the height of the stamping.

If the drawing tool has a blankholder, the force of the latter should be adjusted. For small-size tools (used in presses of up to 60-ton capacity), a rubber or spring cushion is used as a blankholder. Therefore, at the starting moment, the minimum force adequate for holding is to be provided,

since in the course of drawing the blankholding force will grow.

After testing, the tool is finally secured with the slide down and a few trial stampings are made.

To remove the tools, the crankshaft is turned by hand till the slide is in its lowermost position. In pneumatically controlled presses, the slide is brought down by pressing against the push button "Brief operation". When the top and bottom parts of the tool are closed, loosen the nuts of the clamp which secures the shank of the tool top part. Raise the slide, tapping slightly against the upper shoe by a copper hammer.

After the top of the tool has been released and the slide raised into the upper position, unscrew the bolts and remove the plates securing the bottom part of the tool.

Mounting and adjusting large-size tools. The mounting and adjustment of tools for presses of more than 100-ton capacity is a time-consuming process. This procedure is basically similar to that used for moderate-size tools, but there are some special features.

The closed tool is lifted by a lift truck or an electric hoist to the level of the press bed and inspected; the bearing surfaces of the shoes are wiped clean, then the tool is placed on the bolster with one edge and on a support with its other edge. Then the edge of the tool overhanging from the bed is slightly lifted with the hoist and pushed in on the bolster. Now the tool is moved with jimmies over the bolster till the slots and holes for fastening bolts and cushion stems match.

When mounting tools provided with cushions, the cushion pins must be aligned with the holes in the lower shoe. Prior to installing the pins, allow air to escape out of the cushion cylinders. Compare the length of the pins being used with the stroke of the cushion plate. If the pins are shorter than the plate stroke, the plate is not lowered; the pins are installed in the bolster holes; wooden blocks, higher than the pin ends protruding over the plate, are placed on the bolster; then the tool can be mounted. The top part of the tool is bolted to the slide, the top and bottom parts of the tool are joined by cramps, the slide is

raised 0.5-1 millimetre by the shut-height-adjusting drive, the blocks are removed, and the tool lowered.

To prevent the pins from falling down under the press bed at a run of the cushion exceeding the pin length, it is advisable to use pins with heads which remain in the bolster holes when the cushion plate is down. Then the pin length in any case corresponds to the stroke necessary for the given press tool. Besides, the pins are to have a piloting section to facilitate the mounting procedure. The lower shoe is placed with its holes over the piloting sections. When in its upper position, the cushion plate should rest against the bed so as not to transmit the force to the bottom part of the tool, otherwise the fasteners may break and the lower shoe will tear away from the press bed, or the knockout or blankholder may be ruptured.

The cushion pins can be set in the press tool, which makes the adjustment easier and obviates the need of selecting the pins of the required length and setting them in place; on the other hand, the mounting of the tool in the press becomes more difficult, since massive tools are difficult to place aligning their several stems with holes in the press bed.

When a closed large-size tool is mounted in the press, the slide is inched down by electro-pneumatic controls. The shut height of the press is adjusted with due account to the clearance between the slide and the top of the tool. Then the clearance is eliminated by switching on the adjustment mechanism for short-time duty, the pitman run being increased by turning the screws in the pitmans.

For attaching the press tool to the press, first the top part of the tool is secured to the slide, then the bottom is fixed to the bolster. If the guide posts begin rubbing due to misalignment, the bottom part of the tool is loosened, aligned at idle strokes of the press, and again secured with clamps. The top of the tool is bolted with no clamps. When making the tool, its fastening holes are drilled in accordance with the position of the press slide bolts as specified in the flow sheet and press certificate.

Drawing tools for double-acting presses are normally adjusted and fitted without removing them from the presses. They should be removed from the presses only for additional machining on stationary metal-cutting equipment.

Adjustment of drawing tools involves fitting the contact surfaces (faces) of the dies and blankholders; fitting the shaping surfaces of dies and punches and providing necessary clearances between them; trial stamping; and mounting the stops.

The fitting of the contact and shaping surfaces is tested by paint spots left on the die. Used as the painting material is blueing or carbon black diluted in machine oil and applied in a thin coat. The fitting operation is performed with miniature air grinders provided with a set of mounted wheels. When the fitting is over, the surface bears uniformly spaced spots.

The draw clearances are tested with strips of a sheet material whose thickness is equal to that of the workpiece to be stamped. Partial over-squeezings and indents seen on the surface of the strips testify to the zones of inadequate clearances, which should be enlarged with a grinder.

When mounting drawing tools, the blankholder also needs adjustment, since the pressure it exerts has much bearing upon the drawing quality. The blankholder pressure is regulated under trial drawing.

If the pressure is too low, warps may arise on the flange of the drawing and, consequently, the stock drawn into the die is ruptured. Too strong a pressure also causes rupture of the metal, most usually at the border between the cylindrical surface of the drawing and the bottom.

When adjusting press tools, the slide stroke should be so adjusted as to allow a free withdrawal of the ready article from the open tool.

9.14. Testing Press Tools and Remedying Faults

The die-making fitter is expected to detect faults of press tools which may result both from poor workmanship involved and from wrong mounting and adjustment; to do so, he must know the causes of faults and the methods of their remedy.

Testing a press tool should not be confined to making a small number of stampings, since this will not give a full idea of the tool performance. It is necessary to produce at

least 50 or 70 stampings. If all of them are of good quality, the tool may be removed from the press.

A wrong installation of the tool in the press is a source of many defects in finished products.

An immediate indication of a wrongly mounted tool is a unilateral friction of the guide posts, a bright surface of the cut on one side of the part (a witness of an inadequate clearance from that side), and rapid blunting of the cutting edges of the punch and die at that area. This fault is normally due to a misaligned bed, non-parallel or nonuniform spacers under the tool, or shifting of the top part of the tool with respect to the bottom.

Misalignment of the press bed and inaccurately sized spacers can be detected by releasing the fastenings of the lower shoe and measuring the clearance between the tool and the press bed by a feeler gauge. Another method of detecting misalignment consists in turning the press tool through 180°, securing it in the press, and again performing a few blanking operations. Misalignment will reveal itself in friction on the opposite side of the guide posts and by the appearance of the burrs on the other side of the workpiece.

The die may be shifted with respect to the punches when the tool installation on the press follows a wrong sequence: first the lower shoe is fixed and then the upper part of the tool. In this case, a gap may be left between the tool shank and the slide bearing plate. After clamping the shank with the slide jaw, the upper part of the tool will be displaced, eliminating the gap. In dies with guide posts this will result in bending of the guide posts and their unilateral friction against the bushings, which, in turn, will cause burrs to occur on one side of the blanked parts. In dies with no guide posts, the cutting edges of the dies will be damaged by the punches, burrs will occur, the heel blocks will wear rapidly, and the punches will soon get loose. All these defects can be remedied by mounting the tool in the press again and with a greater care.

A strip of stock bearing earth, sand, etc. causes rapid abrasion of the cutting edges and blanking of incompletely-shaped parts (because the strip does not reach the stops), which may result in a breakdown or loosening of the punches

and jamming of the strip (due to its varying width) in the passage between the guide bars. A wrong geometric form of the parts is also possible due to the misaligned narrow strip.

Poor performance of a press tool as a result of low workmanship involved in its manufacture may be the cause of the following faults.

Wrong size or shape of the part. This results from errors occurring in the drawings of the press tool or from ignoring the data given in the drawing. Correct the tool working parts, lap them, or make new ones.

Bent workpiece. This results from the absence of taper in the die port, a narrow port at the outlet, excessive clearance between the die and knockout, or poor design of the knockout. Remedy the tool faults.

Burred surface of cut. The burrs arise when the punch-to-die clearance is too large or nonuniform, or the cutting edges are blunt. Remedy by using a new punch (if the clearance is too large or the punch is tapered), correct mounting of the punch (if the clearance is nonuniform), cold working of the die (if it is non-hardened) with subsequently grinding it over the surface, repeated heat treatment of an inadequately hardened punch or die and its sharpening.

Uneven surface of cut. This is due to inadequate clearances. Increase the clearances by grinding the punch or enlarging the shaped port of the die.

Clogged die port. This is due to misalignment of the ports in the die and the lower shoe, the fault likely to cause rupture of the die. Widen the port in the die plate.

Jammed strip. The strip gets jammed due to an inadequate clearance in the passage behind the trimming punches. Grind the guide surfaces of the rails to provide a larger clearance.

Wrong pitch. As a result of this fault, the strip bears pointed or rectangular barbs, preventing its progress to the stop. The cause of the fault is the rounding of the edge where the two cutting surfaces of the trimming punch meet or the appearance of the clearance between the stop and the cutting surface of the trimming punch. The fault may also be caused by displacement of the stop or by crumpling its working surface due to impacts. The fault is remedied by resetting the stop or by remaking the tool.

Dented cutting edges of the press tool. The dents appear due to excessive clearances between the punch and the heel block or between the bushings and guide posts, or due to wrong mounting of the punch relative to the die, or else due to non-parallelism of the tool shoes. Change the components or reset the punch.

Press tool does not close smoothly. The cause is in that the guide posts are too tight in their bushings, the axes of the guide posts and of the shank are not perpendicular to the bearing surfaces of the tool, the punch bends when entering the port of the heel block, the punches are wrongly mounted in the punch retainer, the ports are misaligned or the shoes of the tool are non-parallel. Remake the tool components.

Punches are torn away. The fault is due to poor attachment of the punches in the retainer, excessive force developed in knocking out the finished stamping or scrap from punches with positive draft, or due to punches being too tight in the heel-block ports. Remedy by correcting the punches, safely upsetting them in the retainer, and widening the heel-block ports.

Workpiece is displaced in bending or ruptured in drawing. The cause of the fault lies in inadequately adjusted pressure exerted by the blankholder. Adjust the force of the springs, increasing it in case of displacement and decreasing it in case of rupture.

Twisting of the bent section in bending operation. This can be remedied by deepening the die.

Heavy imprints on the shaped surface. This defect is accounted for by the punch badly fitted to the die (or vice versa). Fit the shaping surfaces to one another, observing a uniform clearance.

Puckers and warps on drawpieces. Increase the blank-holding pressure.

Buckling or splitting on bent flanges. To combat waviness, the punch-to-die clearance should be decreased, to preclude scores it should be increased.

Bottom of drawpieces humped. Provide for air to escape from the tool by drilling a hole in the punch and upper shoe.

Bright traces on drawpieces. If these occur over the en-

tire circumference, increase the clearance; if only over the generatrix, align the die and punch.

Blank will not set properly on the locator. Check the blank and fit it additionally.

Blank flange of varying width. The fault is due to the blankholder stems of dissimilar length, developing uneven pressure upon the work. Use stems of equal length.

Flange displaced relative to the work axis. This is due to wrong locating. See whether the tool has been assembled properly and correct the locating components.

Puckers on the cylindrical surface of a redrawn piece. This witnesses to an insufficient accumulation of metal in the first draw. To remedy, change the process of drawing (make a shallower cup in the first draw).

Wrinkles on the flanges and buckling or puckers on the walls of a rectangular or asymmetrical workpiece. The blank is loose. Change the tool design, introducing stiffening ribs on the blankholder and die.

Bottom of a cylindrical workpiece is not flat. The punch does not press against the blankholder at the end of the press stroke. Increase the height of the knockout.

Chapter 10

Repair of Press Tools and Prolonging Their Life

10.1. Press-Tool Failures and Their Remedies

Depending on the complexity and scope of operations involved, press-tool repair can be classified as routine (minor) repair, medium repair, or general overhaul.

Routine repair is aimed at repairing minor faults, such as resharpening of blunt dies or punches, replacing springs, stops, locators, or piercing punches. This kind of repair is carried out right in the pressworking shop, within a division specially reserved for the purpose.

Medium repair consists mainly in replacing one of the basic working components and several auxiliary ones. This work is carried out in the tool shop.

General overhaul involves complete disassembling of the tool and replacing of a considerable number of basic and auxiliary components. Labour consumption in such repair can amount to 60-75 per cent of that needed to make a new tool.

Under general overhaul, the punches and dies (or their parts), as well as most of auxiliary components, are replaced, but the upper and lower shoes are used again.

Prior to repair, the tools and faulty components are carefully inspected to determine the type and cause of fault and prescribe the repairing procedure. When doing so, a sheet of faults is made up or a certificate is written describing why the tool was rendered inoperative.

If the press tool was broken as a result of an accident (for instance, breakdown of the die) and the repair involves changes in the design, then the repair drawings should be made up and a new manufacturing process worked out for production of the parts to replace those out of order.

When working out the process of general overhaul, the first thing to decide upon is whether the repairs of the tools are reasonable, since the labour to be consumed for repairs may often nearly amount to that necessary for making a new tool, while the life of a reconditioned tool is always shorter than the life of a new one.

The labour consumed in repair should be reduced by using available components instead of making new ones. For instance, a fractured die can be repaired by forcing a case of non-hardened or case-hardened steel over it.

In repair of press tools, machine operations account for about 35 per cent of labour, the remainder of 65 per cent being bench jobs.

Irrespective of the tool design, the following repair cycling is applied: every ten minor repairs are followed by one medium repair, and every two or three medium repairs are followed by a general overhaul. The total number of repairs depends upon the type of tool and the material of its components.

Table 10 describes typical defects of stampings and troubles encountered in pressworking practice due to faulty tools. The table also gives the remedies.

Some of these troubles are similar in nature and causes

to those arising due to poorly manufactured tools, but their remedies differ since they concern tools that have been used.

No matter what type of repair, the fitter has to remove the upper shoe from the posts. This can be conveniently done with the aid of the device shown in Fig. 113.

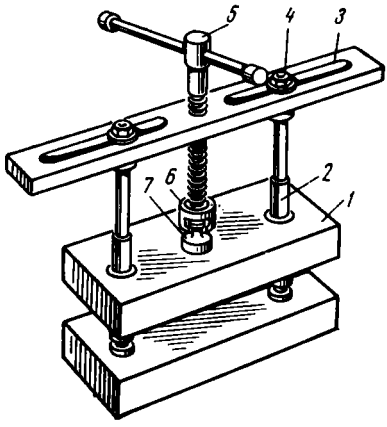


Fig. 113. Upper-shoe remover
1—upper shoe; *2*—guide posts; *3*—plate; *4*—uprights; *5*—screw; *6*—adapter; *7*—tool shank

The device is intended for removing upper shoe *1* from guide posts *2*. This device can be mounted quickly; when using it for removing the shoe, the posts remain aligned with the bushings.

The slots in plate *3* of the device allow free movement of uprights *4* and their fixation in the required position. In the centre of the plate there is a hole with a double-start thread. This hole receives screw *5* with floating adapter *6* at the end, whose projections hug tool shank *7*. When the handle of screw *5* is turned, the projections of the adapter catch hold of the shank and draw shoe *1* upwards, while uprights *4* rest against posts *2* and lower them smoothly and straightly.

10.2. Wear and Reconditioning of Press-Tool Components

In blanking and piercing tools the punches and dies are considered worn out when their cutting edges get blunt. This wear can be eliminated by re-sharpening of their working parts. If the tool is normally worn, the re-sharpening removes 0.10-0.15 millimetre of stock. This means that the tool can stand 15 to 25 re-sharpenings before its punch or die is completely worn out.

Table 10

Press-Tool Faults, Their Causes and Remedies

Fault	Cause	Remedy
	Piercing, blanking, and trimming tools	
Burrs on blanked or pierced part	Blunt cutting edge	Grind punch or die face
	Excessive punch-to-die clearance	Fit clearance to normal
	Punch displaced relative to die	Ensure uniform clearance all around cutting contour
	Die parts displaced	Set parts in socket or use keys
	Top of tool deviates from its bottom	Replace guide posts or bushings
Hollow on stamping near pierced hole	Material is not held tight against die	Increase precompression of stripper springs
	Springs too weak	Use stronger springs or use more springs
	Displaced cutting elements	Ensure uniform clearance all around cutting contour
	Large play of posts in bushings	Replace bushings

Cutting edges are dented	Press-slide bearing surface out of parallel with bed plane	Have press repaired
	Tool shoes non-parallel	Grind shoes
	Cutting not simultaneous over punch contour, starting at one side of tool	Grind cutting edges of punch and die to make them parallel
Press jerks when blanking	Cutting force too large, no bevels on die cutting edges	Grind die face and make bevels
Stripper fails to remove stock	Spring too weak	Replace spring
	Bending and forming tools	
	Springback	Change tool working parts to allow for springback
Wrong dimensions of stampings	Workpiece shifts as bending or forming starts	Provide for blankholding
	Bend angle of small-size flanges smaller than required	Shape die bottom so as to ensure adequate compression of bent areas
	Inaccurate locators	Repair or replace locators
Flange splitting	Punch-to-die clearance too small	Enlarge clearance
	Die too soft	Chrome-plate or nitride die

Table 10 (continued)

Fault	Cause	Remedy
Flange buckling (in forming)	Punch-to-die clearance too large	Reduce clearance
	Draw tools	
Bright traces on drawpiece side	Punch displaced relative to die	Align punch with die port
Splitting of drawpiece	Punch-to-die clearance smaller than stock thickness	Enlarge clearance
	Die too soft	Chrome-plate or nitride punch and die
Metal rupture on cylindrical part and bright traces on flanges of drawpiece	Blankholding pressure too high	Reduce pressure
Metal rupture or bottom break-off in redrawing	Same	Same

Wrinkles on flanges and puckers on walls of drawpiece	Wrong lubricant used	Have lubricant changed
	Blankholding pressure too weak	Increase pressure
Skewed face on hollow cylinder drawn without flange	Non-uniform punch-to-die clearance	Ensure uniform clearance
	Knockout small in diameter	Increase knockout diameter
Puckers on walls of rectangular or asymmetrical drawpiece	Wrong blank dimensions	Check blank dimensions against drawing and templet
Rupture of punch- or die-fastening bolts in press stroke	Punch-to-die clearance smaller than stock thickness	Use more blankholder rods; enlarge clearance
Blankholder stops short of punch top after a few initial strokes of press	Blankholder rods bent	Replace rods

A punch worn out for the first time need not be rejected altogether, but can be reconditioned by altering its type or size. This will save metal used in manufacture of punches.

When making or reconditioning press tools intended for blanking of soft materials, the die alone can be hardened, leaving the punch green. When the punch becomes blunt, the top of the tool is removed, and the entire working edge of the punch upset by tapping against by a hammer, thus increasing its working part. Then the top of the tool is put in place and the punch is forced into the die under a press. This imparts the green punch the outline and dimensions of the port in the hardened die. Thereafter the punch edges are dressed to obtain the required clearance and its face sharpened on a surface grinder.

An insert die, after repeated sharpenings, may be ground off flush with the lower shoe. Its life can be prolonged by placing a ground steel spacer under the die and grinding over its working surface again.

Worn-out dies, similar to punches, can be changed for another size instead of being rejected.

Dies with small cracks can be enclosed in a steel case, for which purpose a case is made with internal sizes smaller than the external sizes of the die by the value of interference for shrink fit. The case is heated and press-fitted over the cold die. After the case cools down, it grips tightly the die, thus closing the crack.

Dies with chipped off pieces can be reconditioned by making a close-fit insert (Fig. 114*a*). For this purpose, the die is annealed, the damaged area is cut off (for instance, in the form of a dovetail) and the cutout is filled with an insert of a steel grade similar to that the die is made of. The insert is press-fitted in the die and welded up from the rear (before press-fitting, the welding place is grooved for welding). After the insert has been introduced, the die is heat-treated and ground, and the shaped port is finished.

When punches become shorter due to resharpenings, they can be extended by attacking tips on them. Such punches consist of two portions: the shank and the working part made of alloy tool steel. The worn punch is annealed, holes are drilled and threaded in it for attaching the working

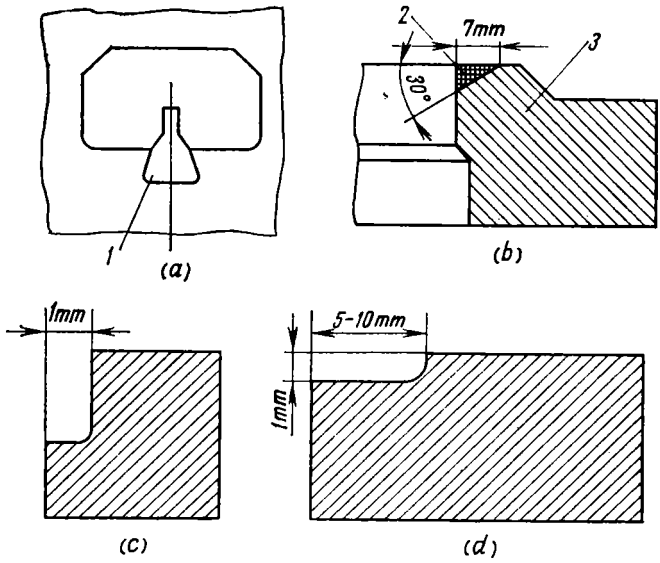


Fig. 114. Methods for reconditioning worn-out dies

a) replacement of broken tooth in die by insert; (*b*) hard-facing of worn-out cutting) edge; (*c*), (*d*) shape of chamfer on cutting edges of cutting-off tools; *1*—insert; *2*—deposited layer; *3*—worn die

part, the latter is fitted to the die, hardened, and secured to the shank. The shank portion is not hardened again. When the working part has worn out, it is replaced, but the shank is reused.

Trimming punches are made with extensions secured by a set plate and a screw. They are reconditioned by changing the extension.

Worn out guide posts are replaced by new ones, and new bushings are provided for them.

10.3. Increasing Press-Tool Service Life

The service life of a press tool is measured in terms of the number of stampings made between sharpening and repair (or between two sharpenings, or else between two repairs). It may also mean the total number of stampings made before the tool is completely worn out.

The life of press tools is dependent upon the following factors:

(a) workpiece design for efficient pressworking;
(b) specific features of the pressworking process;
(c) properties of the stamping material;
(d) design of the press tool;
(e) material of the tool working parts;
(f) workmanship involved in making the press tool;
(g) press-tool operating conditions.

To provide a long service life of a press tool is one of the important tasks while making, repairing, and using press tools. Its achievement offers a considerable saving of time needed for making and repairing press tools, reduces the idle time of equipment needed to replace press tools, and increases the number of stampings obtained by means of one press tool.

The life of tool working parts can be increased by case hardening (nitriding), chrome-plating, hard facing with special electrodes or hard alloys (sormite in case of bending and draw dies and stellite in case of blanking and cutoff dies). Cemented-carbide inserts increase the life of press tools dozens of times.

Chrome-plating is used for increasing the wear resistance of new parts and reconditioning worn parts made from carbon steels. The thickness of chromium layer can be from 3 micrometres upwards (the layer may be 50-60 micrometres in case of reconditioning).

Chrome-plated parts are subject to heat treatment in an oil bath (two hours at 170-180°C).

Hard-facing of tools is aimed at increasing the wear resistance of new, mostly large-size, press tools and at reconditioning worn tools.

Fabrication of dies, hard-faced by electric-arc welding, involves the following operations:

(1) making blanks for hard-facing;
(2) heating-up blanks to 500-600°C prior to hard-facing (necessary for blanks larger than 100 millimetres in diameter);
(3) manual hard-facing;
(4) tempering the hard-faced blank;
(5) machining and bench fitting;
(6) hardening and tempering;

(7) finishing the die.

For reconditioning the working parts of dies made from carbon tool steels (grades У8А, У10А, У12А) use is made of electrodes of low-carbon wire with a special coating that consists of 49 per cent ferro-chrome, 2 per cent black graphite, 16 per cent fluor spar, 11 per cent titanium concentrate, and 22 per cent chalk. The dry coating compound is then bonded with 25-30 per cent liquid glass of a concentration of 1.33-1.34 per cent. The coating is applied by dipping the electrode in it, drying in the air for 12-15 hours and hardening in a furnace (1.5 hours at 180-200°C). An electrode 3 millimetres in diameter requires a coating 2 millimetres thick; for 4-millimetre electrodes the thickness is 1.4 millimetres; for 5-millimetre diameter it is 1.7 millimetres. The current applied is from 80-100 amperes (for 3-millimetre electrodes) up to 170-200 amperes (for 5-millimetre ones).

Figure 114*b* shows the method of die reconditioning by hard-facing the cutting edge with cemented carbides. Worn die *3* is chamfered at an angle of 30° and the carbide facing is performed by arc welding. After layer *2* is faced up it is machined by abrasive or diamond heads to restore the required shape and size of the die.

The working parts of cutoff, piercing, and bending dies are hard-faced by cast hard alloys, sormite-1 and sormite-2, which are made of ferro-chrome carbides and hard solution of nickel, silicon, manganese and carbon in ferrum.

Sormite is hard-faced by oxy-acetylene flame which should be properly adjusted if hard-facing of good quality is expected. Under properly selected conditions for hard-facing the base metal should be brought only to a sweating heat and not melted (appearance of bright moving film, "sweat", on the surface).

Hard-facing proceeds as follows:

(a) the part is inspected, and no hard-facing is performed should any cracks or other damages be detected on it;

(b) the part is annealed for imparting uniform structure to the material (hardened parts are invariably liable to deformation and cracks when hard-faced);

(c) the part is chamfered and recessed over the perimeter of hard-facing; the depth of chamfer depends on the

thickness of the deposited layer (from 0.5 to 2 millimetres); the chamfer at the cutting edge is so made as to be reduced to naught with departing from the cutting edge; when chamfering no sharp edges or coarse lines should be left; the cutting edge width is taken from 5 to 10 millimetres (Fig. 114*c*) depending on the width of the part working surface;

(d) the surface to be hard-faced is cleaned off scale, rust, and dirt till the metal shines;

(e) a rod of sormite 3 to 4 millimetres in diameter is selected; if no such rod is available, a rod of other size is drawn to obtain the required diameter, since the rod size has much bearing upon the quality of deposited layer;

(f) carbon and graphite layers are provided, these are necessary to obtain the correct shape of the hard alloy layer and to protect certain areas of the part from hard alloy;

(g) the part is coated with hard alloy; during work the burner is held at an angle of 25-30° to the surface being hard-faced and the rod perpendicular to the burner flame, the composition of oxy-acetylene mixture should be kept constant throughout the procedure since it influences the temperature of flame.

An excess reduction acetylene flame should be used. Prior to hard-facing, the base metal is heated on the charcoal hearth, in an electric or muffle furnace up to the temperature of 700-750°C. Then the place to be hard-faced is heated by burner flame to "sweating" (till first signs of melting appear on the surface). This very moment the rod is quickly introduced into the flame and hard-facing is done holding the burner at a distance of 3-5 millimetres from the surface. The work should be performed smoothly and quickly enough. The thickness of the deposited layer is from 1.5 to 2.5 millimetres.

Scaling and slag formed in the molten metal should be blown off by the burner flame, and the deposited layer, if uneven, smoothened (by melting the spots with uneven layers of hard alloys).

The hard-faced press tool is placed in warm sand to allow it cool off slowly.

The hard-faced parts are annealed at a temperature of 850-900°C for 2-4 hours and subsequent tempering in oil at a temperature of 450-600°C for one hour.

The annealed pieces of sormite-2 are easily machined by cutting tools and, when hardened, machined by grinding.

10.4. Storing of Press Tools

Proper storage of press tools spells no rejection due to careless handling which, in turn, saves time for resetting the presses. The press tools should never be stored in the immediate vicinity of presses since such storing order makes it difficult to find the necessary tool, encumbers the shop floor space, results in tool components getting astray, and damaged parts.

The press tools should be stored in specially reserved places, the small and medium ones being kept on the tool stands; larger tools are stored on the floor or wooden blocks arranged on the floor so that the tools could be handled by an electric fork truck. Each press tool is stamped with its number, the number of stamping and the index of operation, and the inventory number of the press where the press tool is employed. The numbers of the tool stand and the shelf of the tool room are marked with paint.

If the shop is engaged in production of different articles, one of the non-working surfaces of the tool is painted with certain colour to indicate the article it is used for.

The tool removed from the press and several stampings made last are submitted for inspection to testify whether the tool is suitable for further use, otherwise it should be reground or sent for repairing. The results of inspection are put in the tool card.

All the tools are stored in the closed state. A stamping or a wooden spacer should be inserted between the working parts of the draw and forming tools. Large tools can be provided with several layers of spacers but not more than three. The blanking and cutoff tools should be provided with height limiters. The tools placed at the top should be smaller than those at the bottom.

Tools in good order should be only stored. Out-of-order tools are sent from the pressworking shop for repairing, alternatively they can be provisionally kept within a special floor area reserved for unserviceable tools.

10.5. Safety Rules

Those engaged in assembling and repairing of pressworking dies shall observe the prescribed safety rules.

Prior to assembling or disassembling the tool carefully arrange your place so as to work with safety, examine the bench tools and labour-saving devices and make them ready for use. Never use any chance tools. Check up the tools and devices to make sure they are in good working order.

The heavy tools (over 30 kilograms) should be opened by two workmen or with the aid of hoists. To open the tools (to separate the top from the bottom and to turn them over), the following order is suggested: small tools are dealt with at bench work division, medium and large ones on the wood-covered floor.

The opening of medium- and large-size tools should be supervised by the tool-repairing foreman who has the authority to operate and employ the hoisting equipment and gives orders to the crane man. The tools weighing up to 500 newtons can be handled by one man using a hoist, those heavier than 500 newtons and up to 8 kilonewtons should be handled by two men; one of them aligning the tool, the other slinging the ropes and controlling the hoist (a tackle, telpher, jib).

To open the tools and to disjoin the top and bottom, special devices are used, such as a hook and double-sided striker made to suit the weight of the tools. For instance, smaller tools can be handled by a striker of 30 newtons, medium ones need a striker of 50 newtons, and larger ones that of up to 150 newtons in weight.

No people except those directly engaged in the job should be allowed to where the tool is opened or turned over by hoisting means.

The upper shoe of a medium- or large-size tool should never be put on the edge using a crow bar or any metal rod inserted in the hole of the guide bushing.

For removing strippers, blankholders, inserts, slide blocks, and other heavy components of medium and large tools use is made of special eye bolts whose arrangement and strength are stipulated by the design of the tool.

The eye bolts should be arranged in their places by the fitter prior to assembly.

The components and units which are removed from their places during disassembly should be wiped clean and placed on the bench, mounting plate or special trestles, depending on their sizes and weights.

To remove the members of split dies from the dowels, use is made of a sound chisel, drift and hammer, or auxiliary screws set in specially provided holes.

The guide posts and bushings are pressed out of the shoe with the aid of double-ended strikers: those with the locating part of up to 32 millimetres in diameter are dealt with by a striker of 50 newtons in weight, those with a diameter of up to 65 millimetres will need a striker of 150 newtons or a hand-operated screw press.

When doing and undoing the bolts and screws only those wrenches should be used which perfectly suit the size of the bolt or screw head. If the bolt head is broken and the remainder of the bolt will not go out by being tapped against with a hammer, the broken piece should be extracted by drilling or by welding up a special shank to the bolt body.

When assembling a repaired die, use only those components and units which are in good order, clean, and have no traces of old lubricant.

The units are assembled in the order reverse to disassembly: the piece removed last is mounted first, etc. The components and units of the tool are to be joined accurately and reliably, as required by the design and purpose.

After assembly and fitting of the die it should be carefully examined to see whether anything is left in its cavity; the guide posts should be lubricated with grease.

The work over, tidy up your workplace.

Section III

FORGING DIES

Chapter 11

Hot Closed-Die Forging Processes and Equipment

11.1. Plastic Deformation of Metals

Fundamentals. *Plasticity* is the capacity of a metal to change its shape due to external forces without being destroyed. Some metals and alloys are plastic when cold (plumbum, aluminium), others possess good plasticity only when heated (steel), still others are brittle both when cold and hot (cast iron).

For imparting the required shape to the metal it is given dynamic load and subject to compression stresses which exceed the metal elastic limit but are weaker than its ultimate strength. In this case not only the shape of the blank changes, but also a complex physical process takes place, which influences the metal structure and, consequently, its mechanical and physical properties.

Due to dynamic loads the metal grains can be flattened and crushed to such an extent that the metal structure becomes fibrous. Physico-mechanical properties alter very conspicuously under plastic deformation when metal is cold, i.e., due to cold working. This increases hardness, strength, and brittleness of metal whereas its viscosity, plasticity, and corrosion resistance decrease.

When hot pressed the metal acquires better qualities: it becomes more compact, it develops fine-grain structure which is more uniform than that in cast metal. At the same time metal acquires fibrous structure which underlies its different mechanical properties parallel and cross to the fibres, this being a shortcoming of pressure hot working of metals.

The temperature range of hot plastic deformation varies with metals and alloys. For instance, the upper heating limit for carbon steel is 1200-1000°C depending upon the grade of steel, the lower one being 850-800°C. Pressure shaping is usually begun with the highest temperature and finished with the blank cooled off down to the lowest permissible temperature. The plastic deformation is described by the *degree of deformation* which is a ratio of the difference in blank sizes prior to, and following, the deformation to the initial size, expressed in per cent.

The *degree of deformation* ξ *due to upsetting* (compression) is found from the formula

$$\xi = \frac{h_0 - h}{h_0} 100\%$$

where h_0 = thickness of the blank prior to upsetting
h = thickness (height) of the blank following the upsetting

The *degree of deformation due to drawing* is found from the formula

$$\xi = \frac{F_0 - F_1}{F_0} 100\%$$

where F_0 = cross section of the initial blank
F_1 = cross section of the drawn blank (forging)

Laws of plastic deformation. The basic laws of plastic deformation are as follows.

Minimum resistance law: under plastic deformation the metal particles always move where they encounter the least resistance.

Constant volume law: under plastic deformation the volume of metal prior to deformation is equal to that following deformation, i.e., metal being forged changes only its shape. This law is of much importance, since it underlies the computations of volume, mass, and size of initial blanks and is used for determining the sizes of dies and special tools as used at different operational elements.

Friction law: surface friction due to roughness on the striker surfaces (or surfaces of die impressions) offers considerable resistance to metal flow and causes the zones of hindered deformation. To decrease detrimental effects of

friction upon metal flow, the working surfaces of dies are carefully treated, ground, and polished.

Law of body expansion due to heating: heated bodies expand, cooled bodies contract. Under hot working of metals this is called *shrinkage*.

Enlargement of a blank due to heating is found from the formula:

$$l_{hot} = l_{cold} [1 + \beta (t_{hot} - t_0)]$$

where l_{hot} = length (thickness) of the blank heated to t_{hot}
l_{cold} = initial length (thickness) of the blank under t_0
β = coefficient of linear expansion for the given material
t_{hot} = heating temperature, °C
t_0 = initial temperature of the blank, °C

The computations for steel blanks are more simple, taking into account that the blanks heated from 20-40°C to 1100-1200°C expand by 1.1-1.2 per cent. For instance, if the cold blank length is 400 millimetres, its length under 1200°C is

$$400 + \frac{400 \times 1.2}{100} = 404.8 \text{ mm}$$

The opposite phenomenon, i.e., compression of metal due to cooling should be necessarily taken into consideration when manufacturing hot forge dies.

The die impressions, for instance upsetting recesses, must be larger than the size of a cold forging by the amount of draft, i.e., by 1.1-1.2 per cent in case of steel.

To avoid frequent computations, workers in die-making shops have a *contracting rule* accounting for corrections for metal expansion due to heating.

11.2. Processes Occurring During Hot Deformation of Metals

The basic methods of pressure hot working of metals are: rolling, hot drawing, pressing, smith forging, closed-die forging (Fig. 115).

Rolling (Fig. 115*a*) is squeezing of metal by making it pass between the revolving shafts of the mill.

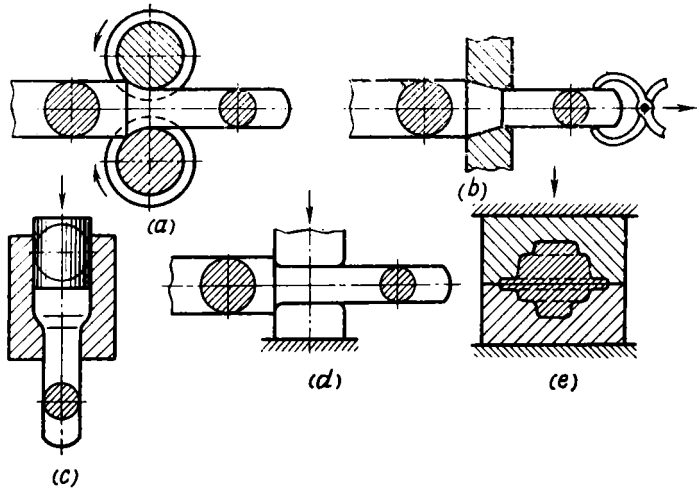


Fig. 115. Pressure hot working of metals
(*a*) rolling; (*b*) hot drawing; (*c*) pressing; (*d*) smith forging; (*e*) closed-die forging

Hot drawing (Fig. 115*b*) is squeezing of heated metal by drawing it through the hole of the corresponding size and shape (round, square, shaped).

Pressing (Fig. 115*c*) is squeezing of metal by forcing it through the die hole of the corresponding shape. If pressing is used for making a blank of a certain part, it is called *hot extrusion.*

Smith forging (Fig. 115*d*) is making a blank by pressing against metal with a hammer or press, the metal being placed between flat dies secured at the bottom and top parts of the hammer or press. A variety of smith forging is *drop forging.*

Smith forging in hammers and presses is performed with the aid of special tools and devices. Much attention should be paid to make accurate forgings, reducing, thus, metal scrap in further machining, and saving time to be spent on it. The forgings which are closest to the shape and size of the product can be obtained by the use of *unattached dies.*

Closed-die forging (Fig. 115*e*) is making blanks in swage hammers and presses by pressing against metal which is

in the die. When being forged the heated metal flows freely to the sides, downwards or lengthwise, while under closed-die forging its flow is restricted by the shape of impression in a die manufactured beforehand for the given job.

Hot forging is now the most popular method of working metal by pressure.

Closed-die forging processes are shown schematically in Fig. 116. The bar stock is delivered from store *1*, after it is tested in laboratory *2*, to the preparatory division where it is cut by shears *3* into blanks of required size. The blanks are then heated in furnace *4* and handed over to be forged in hammer *5* (or friction press). If the forging is performed in the open die, the workpiece is then dealt with in crank press *6* to trim the fin. Thereafter, the forgings are charged into furnace *7* to be annealed. Finally, the forgings are tested for hardness, after heat treatment, in press *8*.

In etching plant *9* the forgings are cleaned off scaling after which they are delivered for coining in press *10*. Now the forgings arrive at station *11* where they are checked up for conformity of their sizes and shape to those specified in the drawings and sent to store *12*. The forging scrap is handed over to waste store *13*.

When making forgings of rather simple shape by hot forging, the dies are used with only one finish impression (Fig. 117*a*). Heated blank *1* is forged in the central area of bottom half member *2* by striking against it with consecutive blows dealt by top half member *3* of the die.

The metal sets up, fills in the cavity of impression while excessive metal is squeezed out into groove *4* producing flash (fin).

The bulk of metal squeezed out as flash locates in the widest area of the groove, i.e., the magazine. If the formation of flash proceeds properly, the impression cavity will be filled up well, precluding breakdown of the die. The flash also prevents forging rejects when the blank forgings vary in size.

The flash is usually cut away right after the forging process while the forging is still hot. This is done in a trimming operation on the crank press.

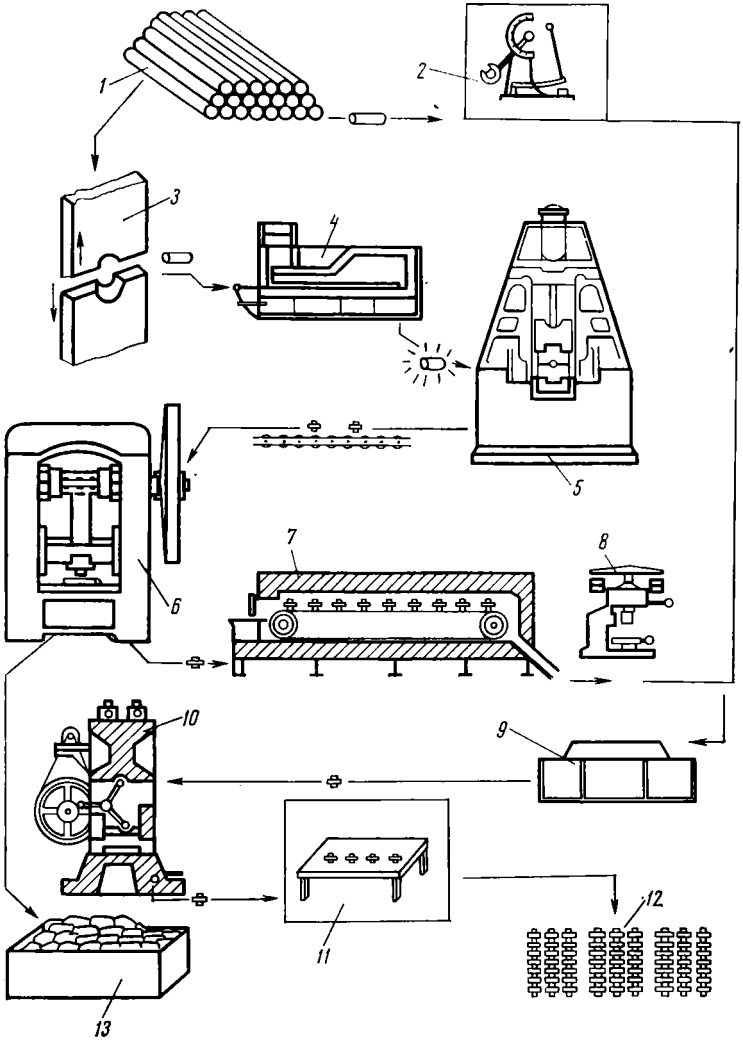


Fig. 116. Diagram showing processes involved in hot closed-die forging

1, *12*—stores; *2*—laboratory; *3*—shears; *4*, *7*—furnaces; *5*—hammer; *6*—crank press; *8*, *10*—presses; *9*—etching plant; *11*—station; *13*—waste store

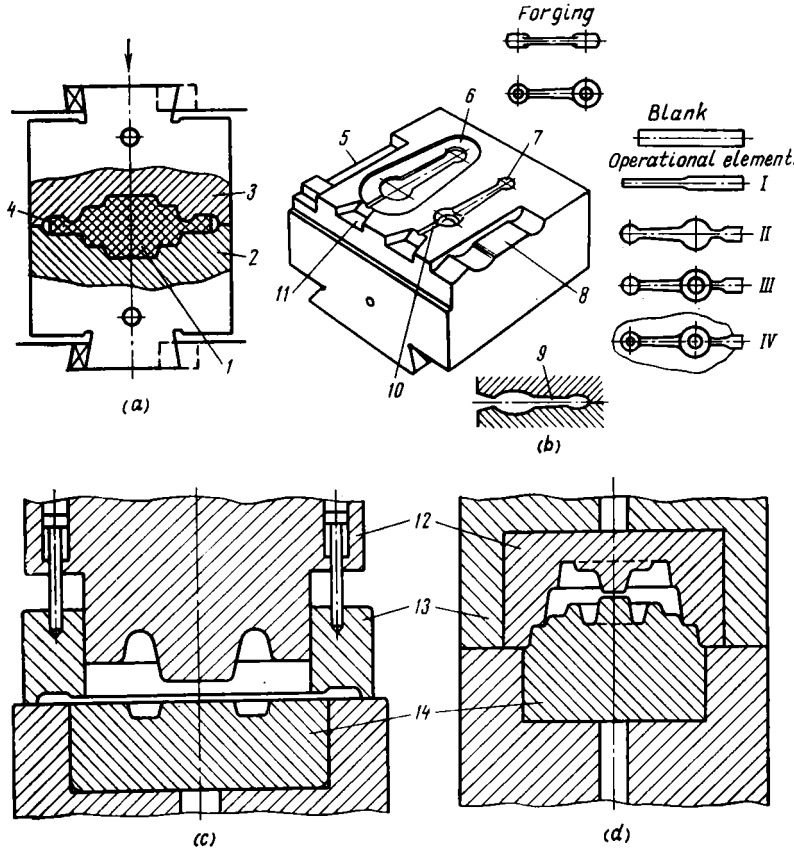


Fig. 117. Different types of dies for hot closed-die forging

(*a*) single-impression drop hammer die; (*b*) multiple-impression drop hammer die; (*c*) die with closed magazine; (*d*) flashless die; *1*—blank to be stamped; *2*—bottom half member; *3*—top half member; *4*—groove; *5*—fullering impression; *6*—finish impression; *7*—semifinish (blocking) impression; *8*—open bender; *9*—magazine; *10*—web; *11*—sprue; *12*—punch; *13*—ring; *14*—bottom insert

The forgings of intricate design are made in multiple-impression dies fitted out with preliminary-preparatory, forming, and sizing impressions.

For instance, a pitman (Fig. 117*b*) is forged in four operational elements: *I*—fullering, *II*—edging, *III*—blocking,

IV—finishing or sizing. Open fullering impression *5* is normally arranged on the left-hand side, and the open bender *8* is on the right. The middle of the die accommodates the closed forming impressions *7* and *6*.

The preliminary-preparatory impressions serve for dealing blows of limited strength since the metal can flow in all directions and deforms quicker. When the metal is in closed impressions its flow is restricted and it flows more intensively along the blank axis. The highest forging force arises at the end of deformation process, i.e., in finish impression *6* where heaviest blows are dealt.

During hot open-die forging the metal wasted as flash comes up to 20-30 per cent. Therefore, measures to reduce flash are of great importance.

Some manufacturers often employ closed dies with small magazines for excessive metal (Fig. 117*c*). This method does not offer obviation of flash but considerably reduces it.

Flashless forging in a die closed all around (Fig. 117*d*) saves metal, obviates the need of trimming dies, reduces allowances for further machining. Flashless forging calls for strict adherence to sizes of blanks for forging, as well as for dies of more complicated design.

To obtain accurate sizes and good surface finish of forgings, which will make further machining unnecessary, the forging process is followed by flat or three-dimensional sizing when the piece is hot, moderately hot or cold.

Under flat sizing the metal flows freely to the sides perpendicular to the squeezing direction. Under three-dimensional sizing the flow of metal being squeezed is restricted. It fills up all the depressions and cavities of the die, the excessive metal being ousted as flash.

Hot sizing is usually of a three-dimensional type. It is carried out right after hot trimming of burrs. The secondary burrs appearing after the sizing are removed (trimmed) in trimming dies after the forging is finally cooled off.

Hot sizing is frequently performed in a finish impression of a forging die mounted in a stamping hammer or friction screw press. The best results can be achieved when sizing on crank hot stamping press in a die specially made for the purpose.

Moderately-hot sizing is done when making forgings of low-plastic steels or when the available press is of low capacity. This type of sizing is also performed on the coining presses with the temperature of forgings not lower than 600°C.

Cold sizing (both flat and three-dimensional) is performed on crank coining presses in special coining dies.

11.3. Hot-Forging Equipment

Hot-forging equipment includes steam and friction drop-forging hammers, hydraulic, power, and friction forging presses, horizontal forging machines, forging rolls.

The forging hammers are classified into steam and power-driven (board drop) hammers.

The steam hammers are double-acting machines, since the metal forged in them is deformed both by the force of falling parts and by pressure of compressed air or steam. The friction-drive hammers are single-acting machines since the metal forged in them is deformed only by the work of the ram falling under its own weight.

Double-acting steam hammers are generally built with falling parts weighing from 6 to 100 kilonewtons and over.

The diagram of a steam forging hammer is shown in Fig. 118. The hammer is erected on heavy anvil *1* which is a massive steel casting weighing commonly 20-25 times the falling weight. The heavy anvil is mounted in the well of the foundation on pad *22* made of oak beams and secured with such beams at the sides. Attached to the heavy anvil by spring-loaded bolts *20* are steel cast frames *19* which are joined at the top by steel bed *5*.

The bolts with absorbing springs secure cylinder *7* of the hammer, which is a steel or iron casting accommodating the working box and two more boxes—slide valve chest *15* and throttle chest *12*. The top of the cylinder is provided with safety cushion *8* precluding rigid blows of the piston against the cylinder cover, which may occur due to wrong adjustment of the steam distributing mechanism. The falling parts include piston *10*, rod *6*, and steel forged ram *3* with top die *2*. The hammer operator controls the hammer by depressing foot treadle *21*. The hammer ram slides down

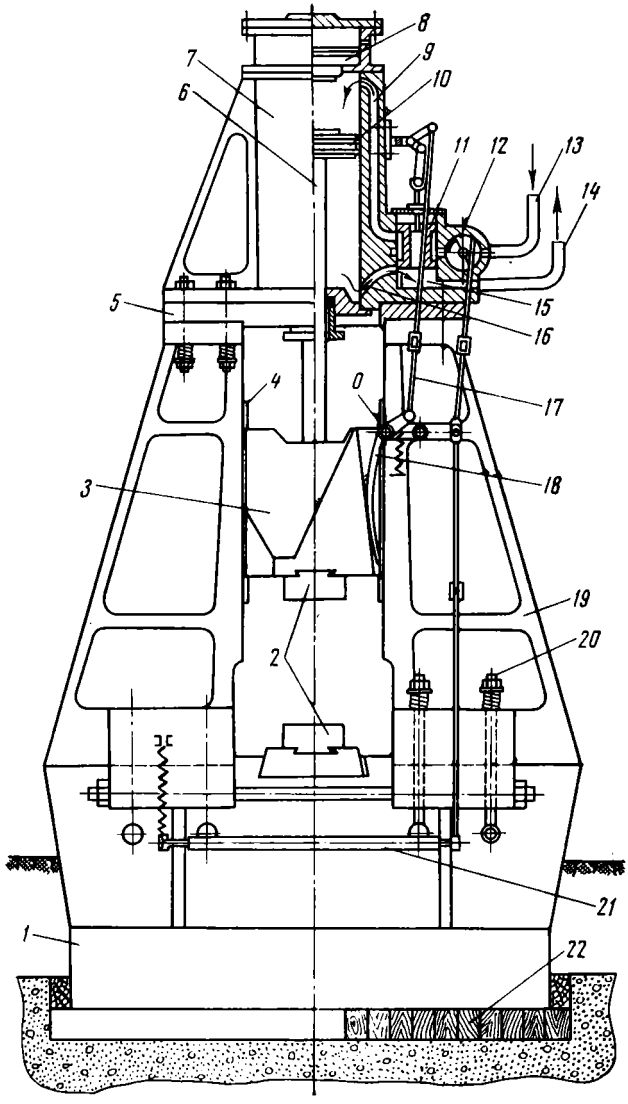


Fig. 118. Steam forging hammer

1—anvil; *2*—ram die; *3*—ram; *4*—V-guides; *5*—bed; *6*—rod; *7*—cylinder; *8*—safety cushion; *9*, *16*—ducts; *10*—piston; *11*—slide valve; *12*—throttle chest; *13*—pipeline; *14*—exhaust pipe; *15*—slide valve chest; *17*—tie; *18*—lever; *19*—frames; *20*—bolts; *21*—treadle; *22*—pad

V-guides *4* secured in frames *19*. The guides are provided with a device for adjusting the clearance between them and the ram.

The hammer can operate with either single strokes of full or partial force, or continuous blows of the ram die on the forging. The forging can also be held down to the anvil or the ram can be held up. Compressed air or high-pressure steam (7-9 atmospheres) is delivered over pipeline *13* through throttle *12* to slide valve chest *15* and therefrom to the upper cavity of ram cylinder *7* via duct *9*. The used air is forced out of the bottom cavity of the cylinder via duct *16* to slide valve chest and farther on to exhaust pipe *14*.

Ram *3* has an inclined bevel over which sword-like lever *18* slides. When the ram ascends or descends, the lever moves to the left or to the right relative to point *0* and moves tie *17* which sets slide valve *11* in its upper or lower position. When the slide valve is in its lowermost position, the compressed air, via duct *16*, gets into the lower cavity of the ram cylinder and lifts piston *10* with ram *3*. When ascending the ram with its bevel makes the sword-like lever turn to the right, as a result tie *17* rises, slide valve *11* sets itself in its uppermost position and the ram drops down. In this way the ram can swing continuously.

To deal a full single blow, it is necessary to press against the treadle abruptly when the ram is up.

The hammer controls allow the blows of different force to be delivered, with the ram performing idle swings between them. The blow depends upon how strongly the treadle is pressed against and where is the ram when the treadle is operated. When forging proceeds in the preliminary-preparatory impressions the operator delivers frequent weak blows, when the work is performed in forging impressions the blows must be infrequent but strong. With the treadle pressed smoothly the ram will descend holding thus the top die against the bottom one.

Depending on the weight of falling parts the hammer can deliver up to 60 blows per minute.

The steam forging hammers can produce forgings weighing from 5 to 1000 newtons. The work is usually done in multiple-impression open dies.

Friction board drop hammers (Fig. 119*a*) are used for hot stamping.

These hammers are designed as follows. Ram *5* is attached to oak board *1* which is moved up by rotating rolls *2*. As the board and ram reach the top of the stroke, the rolls separate, the board is released and held in this position by brake cams *3*. When treadle *6* is depressed, the cams are moved apart from each other and the ram falls at once to strike the forging. Then the rolls are brought to each other again and raise, thus, the ram. The force of blow can be adjusted by varying the distance of fall by means of cam *4*.

The falling weight in the board drop hammers is usually from 5 to 15 kilonewtons. The hammers of new design are provided with an adjuster of ram blows delivered during stamping operations. Such hammers are employed for making small forgings, mainly in open dies, as well as for cold straightening of stamped forgings after the flash is cut away. The hammers operate at 40-60 blows per minute.

Apart from friction board drop hammers, the hot stamping shops are supplied with *friction screw presses* for stamping in open and closed dies (mainly single-impression ones) to make the parts from bars or strips. These presses are also suitable for hot sizing and cold coining of parts made in hammers. The friction screw presses are available in the capacity range from 630 kilonewtons to 2.5 meganewtons and occasionally up to 6 meganewtons.

The design of friction screw presses was described in Chapter 7. Such presses operate at 11-25 strokes per minute; they are less efficient than forging hammers.

Crank-type forging presses employ the same operating principle as the cold stamping crank-type presses described in 7.1.

Unlike the latter, they have a frame of a more rigid design and a more powerful drive. The press bed has a V-shaped structure. The upper surface of the bed is, as usual, horizontal and the lower surface is inclined at an angle of 10 or 14° and rests against the frame surface bevelled in the same way. Owing to the bevel the bed can be lifted and lowered. This allows the dies of different height to be mounted and the bottom of the die to be adjusted with respect to the top. The knockouts in the bed and the slide provide

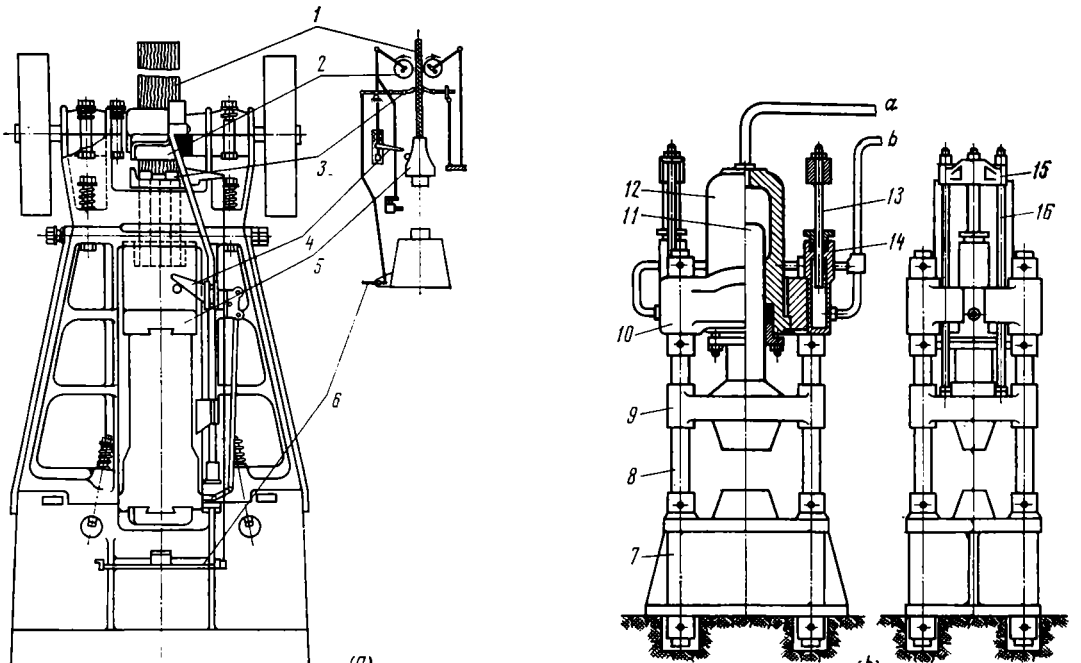


Fig. 119. Friction board drop hammer (*a*) and hydraulic hot forging press (*b*)

1—board; *2*—rolls; *3*—brake cams; *4*—lift height variation cam; *5*—ram; *6*—treadle; *7*—lower crosshead; *8*—column; *9*—crossover; *10*—upper crosshead; *11*, *13*—crossover lift plungers; *12*—main cylinder; *14*—lift cylinder; *15*—lift crosshead; *16*—tie rods

for automatic pushing of the finished forging out of the die impression, this makes it possible to reduce the stamping drafts.

The crank-type forging presses can perform forging in dies with flash around the parting line, extrusion stamping, piercing stamping, and different combined stamping operations. To suit various operating conditions, the crank-type forging presses are available with the tonnage of 6.3 to 80 meganewtons, operating minimum strokes per minute of 90 (6.3-meganewton press) to 35 (80-meganewton press).

As compared to hammer forging, the press stamping offers the following advantages: accuracy of forgings, smaller stamping drafts, high efficiency (three times as high as that obtained in hammer forging), possibility of mechanical and automatic feed of blanks in the die and the removal of forgings therefrom, sparing consumption of power, safe operation, no violent impacts during work.

Hydraulic hot forging presses are employed for the following jobs: stamping in closed dies (often in those with split female dies), piercing stamping, drawing the pierced blanks through the rings, stamping in dies with flash around the parting line.

A hydraulic forging press is shown schematically in Fig. 119*b*. Lower crosshead *7* mounts four columns *8* while the crosshead itself is erected on the foundation. The tops of the columns are joined with upper crosshead *10* carrying main working cylinder *12* with plunger *11* connected to movable crossover *9*. The crossover travels over the columns as if over the guides. The upper crossover receives the top of the die. The bottom of the die is attached to the lower crosshead.

The operating fluid (oil) is pressure-fed through pipe *a* to cylinder *12* and presses against plunger *11* which descends to impart pressure to crossover *9*. The die connected with the crossover deforms the forging. The upward travel of the crossover is carried out by lift cylinders *14* mounted in the upper crosshead. For this purpose the operating fluid is, through pipe *b*, delivered to the lift cylinders. The fluid exerts pressure against plungers *13* which ascend to move crossover *9* connected with the plungers via crosshead *15* and tie rods *16*.

The hydraulic presses are preferably used for stamping complicated large forgings in multiple-impression dies. This is why they are made with four columns, provided with spacious top and bottom plates. Hydraulic forging presses can develop a force of 5-150 meganewtons. The presses with the force of over 8 meganewtons are equipped with moving beds allowing the forging to be moved under the top die forward and backward. Such presses can produce forgings 700 kilograms and over in mass.

Horizontal forging machines are similar in design to crank-type hot forging presses but they are mounted horizontally.

Such machines are intended for hot upsetting and piercing of forgings from bars 13 to 250 millimetres in diameter in multiple-impression dies. They are mainly suitable for manufacture of all kinds of parts with stems and shoulder at the end or in the middle, with or without a hole in the face (such as bolts, pins, ties, axles, valves), as well as nuts, bushings, blank caps for gear wheels, etc.

As compared to hammers and presses the horizontal forging machines are most efficient. They yield forgings of more accurate sizes, without flash and with little stamping drafts.

The machines are available with the working force of 1-30 meganewtons and over, the force being developed at the end of the slide stroke.

Figure 120 is a general view of a horizontal forging machine with a force of 4 meganewtons and its operating cycle. The heated end of bar *3* is inserted in the appropriate impression of stationary RH die *4* secured in machine frame *5*. The bar is positioned by means of stop *6*. When the machine is switched on for working strokes, movable jaw *1* starts travelling together with movable die *2* and slide *8* of the machine with punch *7* (position *I*).

Before the punch touches upon the projecting end of bar *3*, movable die *2* presses the bar against stationary die *4*, whereas stop *6* interlocked with the central slide is retracted (position *II*). The result of the further movement of the slide will be that punch *7* will upset the bar end overhanging beyond the clamping portion of the die until slide *8* reaches the frontmost position. Now the metal will fill

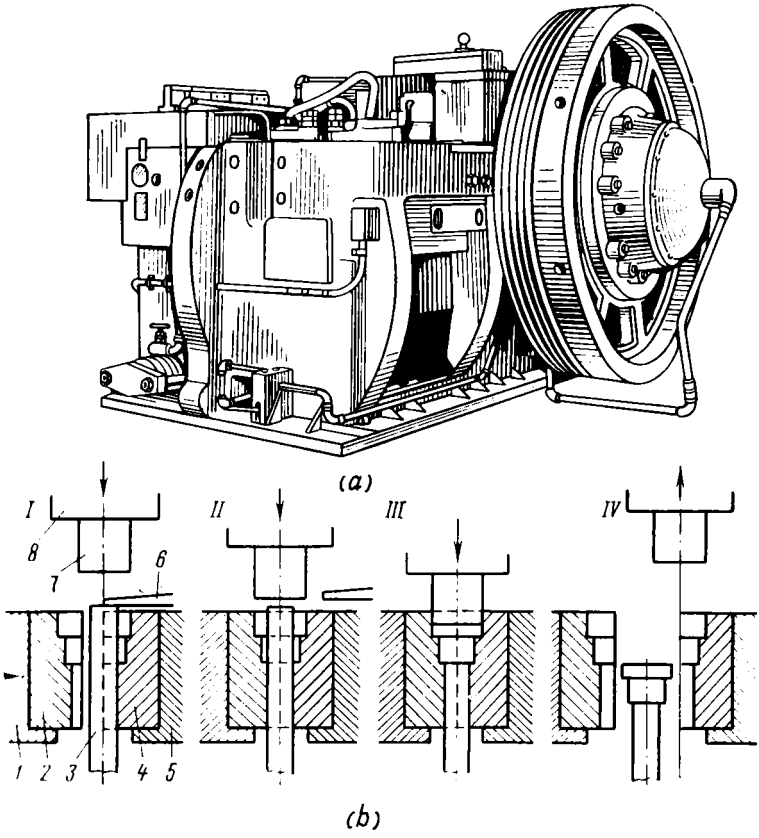


Fig. 120. Horizontal forging machine (*a*) and its operating cycle (*b*)
1—jaw; *2*—movable die; *3*—bar; *4*—stationary die; *5*—frame; *6*—stop; *7*—punch; *8*—slide

up the cavity in dies arranged in front of the clamping portion (position *III*).

The shaping cavity can be provided not only in the die but also in the punch (in addition to that of the die), alternatively the punch alone can have the cavity.

In its frontmost position, the slide starts its return travel, and the punch goes some distance out of the die cavity,

the dies then move apart and the upset piece is removed, or it drops, out of the die, the punch and die returning to their initial positions (position *IV*).

Chapter 12

Forging Die Design

12.1. General Requirements

The dies are designed and made according to the forging drawing which is made up proceeding from the drawing of a ready article taking into account the following: machining allowances, forging tolerances, overlaps if necessary, corner radii, stamping drafts. It must also be decided where to locate the parting line of the die.

The *machining allowances* per side are found from the tables and selected to suit the accuracy to be involved in manufacturing the forgings and the surface finish in ready parts. The smallest allowances are prescribed for stamping in presses, larger allowances are taken for hammer forging and for work on horizontal forging machines. Besides, if the surface finish of ready articles is expected to be of high standard, the allowance is increased by 0.3-0.8 millimetre per side to provide enough stock for grinding.

The forging drawings bear the finish sizes of the machined parts indicated in brackets (Fig. 121*a*).

The *forging tolerance* is the value of permissible deviation from the nominal forging size indicated in the drawing. The tolerances should be valid for all the sizes of stamped forgings made in closed dies, including the sizes related to the surfaces not to be machined. Depending upon the requirements extended to the machined parts, four groups of accuracy in manufacturing stamped forgings of ferrous metals are stipulated.

The first group includes forgings with the least allowance and closest tolerances.

The accuracy involved in making forgings of the second and third groups is lower.

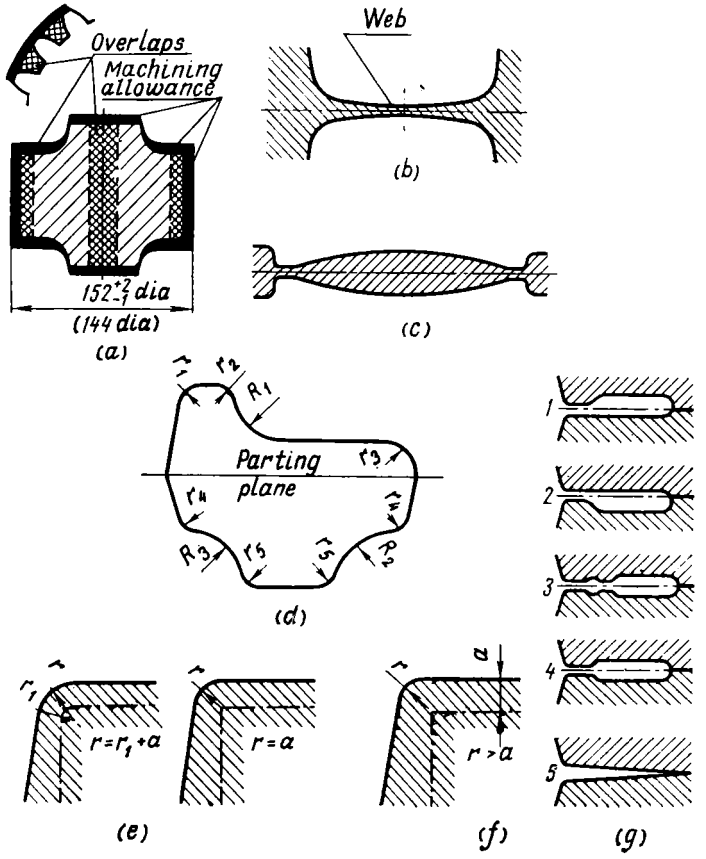


Fig. 121. Forging drawing

(a) overlaps, allowances, and tolerances; (b), (c) shapes of webs; (d), (e), (f) fillets and corner radii; (g) shapes of flash gutter; 1—standard gutter, 2—for trimming flash with turnover; 3—with barrier; 4—with larger magazine; 5—wedge-type

The forgings of the fourth group are the most accurate, this being achieved by hot coining applied to the forgings of the former three groups.

In prescribing the forging tolerances, the possible wear of dies is accounted for since the wear influences the given size.

Overlap is the stock left on the work where forging is inconvenient, this stock projects beyond the outline of the ready article (see Fig. 121*a*). Overlaps are resorted to for the sake of simpler shape of the forging to facilitate its manufacture. In further cutting the overlaps are removed.

The parts with through holes cannot be made by hammer stamping or in the press with the hole pierced through. This is why the hole is only marked and the film (web) is left which is pierced when trimming away the flash (Fig. 121*b*). Figure 121*c* shows the shape of the web with a large-diameter hole.

Fillets and corner radii. Adequate radii are required where two surfaces of a forging meet. Nominal fillets and corner radii are taken from the tables to suit the weight and required accuracy of forgings. Sharp fillets and radii increase the tendency towards forging defects and accelerate the die wear. To avoid this the fillets R are taken to be larger than the corner radii r (Fig. 121*d*).

In sharp edges of parts corner radius r should be equal to the amount of allowance a taking into account chamfers, the fillets and corner radii in the finish drawing (Fig. 121*e*). It is not permitted that the radius be smaller than the allowance per side (Fig. 125*f*).

Draft is the taper put on all the forging sides arranged parallel to the travel of the press slide or hammer ram. This makes it easier for the metal to fill up the working volume of die impressions and facilitates the removal of the forging.

Standard practice indicates the use of 3-10° draft angles depending on the type of die, rib height, and the material to be processed; the drafts are found from the tables. The forgings of non-ferrous alloys need smaller drafts than the steel ones.

The descriptions of forgings often contain the terms referring to the areas of forgings, these are: a shoulder, recess, projection, pocket.

A *shoulder* is an area of the forging with an enlarged cross section and the length equal to, or smaller than, $0.3D$ (D is the diameter or larger side of the rectangular shoulder).

A *recess* is a forging area with the cross section smaller than the adjacent one.

A *projection* is a forging area with the cross section larger than the adjacent one.

A *pocket* is a forging area with the diameter or side smaller than those of two adjacent areâs.

The *parting line* is selected while designing the forging, the main requirement being easy removal of the forging out of the die. For making complex forgings when the parting line cannot be made in one plane but is a complicated surface including horizontal and inclined planes, the slope of the forging with respect to the horizontal plane is determined taking into account self-balancing of shearing forces under stamping.

Flash gutters. The volume of a blank is always larger than that of the ready article (stamped part). Excessive stock compensates for inaccuracy likely to occur in cutting off a blank, errors in mounting the die; it also softens the impacts when half members of a die close. Besides, excessive stock assists in filling up the die cavity: when the metal flows out into the clearance between the die half members, it produces flash which sets up quickly and prevents further escape of the metal into the clearance. To allow the metal to locate in flash, a flash gutter (Fig. 121*g*) is relieved.

The area of the gutter adjacent to the impression cavity (a bridge) is of a minimum height. The wider area of the gutter (magazine) is usually made in the top section of the die (form *1*). If the forging is of such a shape that it must be turned over through an angle of 180° when trimming the flash away, the magazine is made at the bottom (form *2*). For greater slowing down of metal (to allow it to fill up the impression cavities better), the bridge of the gutter is made with a barrier (form *3*). If much metal is expected to flow to flash, a larger magazine (form *4*) is provided. A wedge-type gutter (form *5*) decreases the flash.

12.2. Types of Dies

According to the types of equipment they are used on and the operations they are intended for, the dies are classified into:

(1) hammer, sizing, straightening (for drop forging hammers);

(2) stamping, straightening, sizing (for hot forging presses);

(3) upsetter, stamping, straightening, sizing (for friction presses);

(4) upsetter, bending, notching (for forging machines);

(5) rolling (for forging rolls);

(6) simple cutoff, broaching, combination cutoff (cutoff and broaching, cutoff and straightening), special-purpose for cutting off fin, for cutting away drafts, etc. (for trimming presses);

(7) coining (for coining presses).

For the sake of simplicity all the dies for hammers are termed *drop hammer dies*, those for crank-type forging presses are known as *press dies*, the dies for horizontal forging machines are called *upsetter dies*, those for trimming presses are *trimming dies*.

The dies are also classified from the standpoint of their manufacturing process: open dies (for flash stamping) and closed dies (for flashless stamping).

As to their design the dies fall into the tools with one parting line, with two parting lines, with a knockout, one-block, sectional, with inserts, etc.

The dies can be either of single-impression or multiple-impression type. The former are used for making simple-shaped blanks and blanks previously handled on hammers (by smith forging or in unattached dies), or by rolling in forging rolls. The multiple-impression dies are used for making intricately-shaped forgings. With such dies all the operations are performed on one heating of the forging stock.

Drop hammer dies. These can be either single-impression or multiple-impression tools.

The diagram of a single-impression die can be found in Fig. 122 (*a-e*). The die comprises two parts: bottom *5* and top *8*. The top is attached to hammer ram *10* by its shank and wedge *9*. Slide block *11* is used for precluding displacement of the die. The bottom of the die is attached by its shank and wedge *4*, in die holder *3*, the latter being, in turn, secured to the stationary part of the hammer, i.e., anvil block *1*, by wedge *2*. Slide block *14* serves for preventing the bottom of the die from displacement.

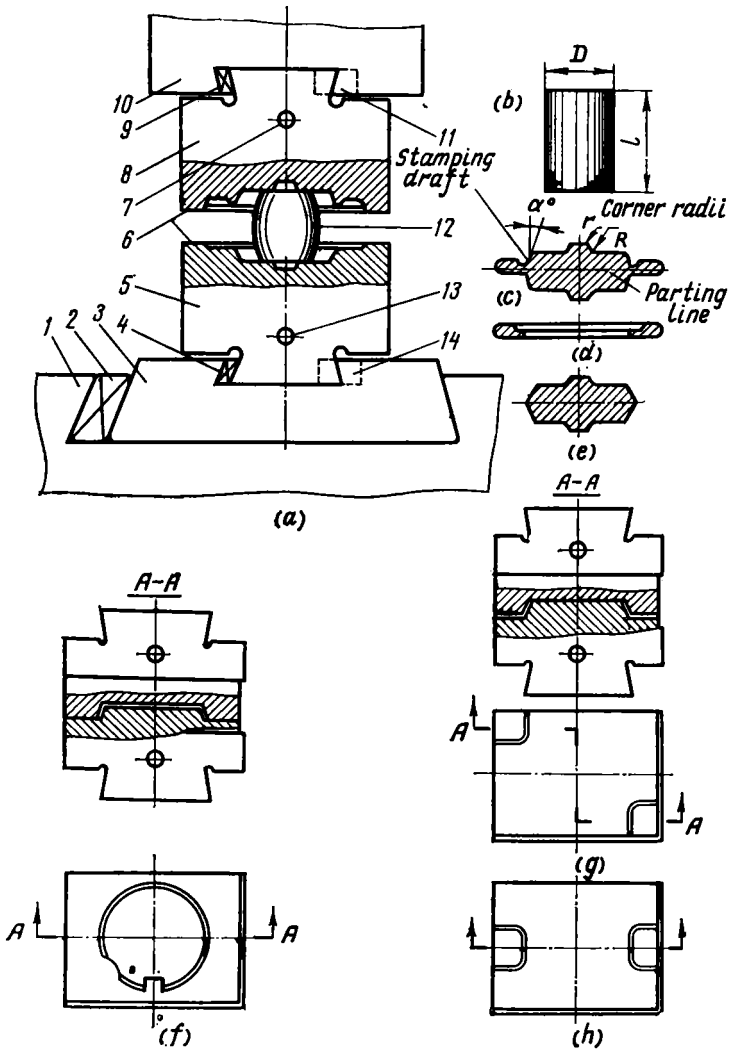


Fig. 122. Single-impression hammer die

(*a*) die; (*b*) forging blank; (*c*) burred forging; (*d*) burr after trimming; (*e*) forged article; (*f*) round lock; (*g*) tennon corner locks; (*h*) tenon axial locks; *1*—anvil block; *2*, *4*, *9*—wedges; *3*—die holder; *5*—the bottom part of die; *6*—parting plane; *7*, *13*—handling holes; *8*—the top part of die; *10*—ram; *11*, *14*—slide blocks; *12*—forging blank

The face of the two surfaces of the die is relieved, i.e., provided with impressions answering for the shape of the future forging, all the depressions are rounded off to a certain radius. To avoid cracks, a small clearance is made in the corners and in the middle of the shank, between the die shoulders and the ram or between the shoulders and die holders, the clearance ensuring the thrust for the die when the impacts are delivered only against the shank surface. The slot for slide block *14* is always made of the same height as the level of the die shoulder.

Stamping may sometimes develop side forces tending to shift the top part of the die with respect to the bottom one, thus deteriorating the die accuracy. To counteract these forces, the drop hammer dies are provided with guide locks. Figure 122 (*f*, *g*, *h*) shows the designs of dies with a round lock and tenon locks.

Crank-press dies. The feature of such dies is that the die cavity is filled up with heated metal with one press stroke. This is why the metal is deformed in a press to a larger extent than in a hammer which calls for dividing the stamping operation into several operational elements.

Another feature of press stamping is connected with the constant value of the press slide stroke; as a result the surfaces of the top and bottom parts of the die cannot fully contact each other and, therefore, are to have a clearance equal to the thickness of flash.

The dies for crank-type hot forging presses comprise two blocks: top and bottom ones. The blocks include the following units and parts: shoes, holders, guide posts, post bushings with scale-proof collars, impression inserts, impression insert plates protecting the shoe and holder against warping, fasteners for impression inserts, and mechanisms for removing the forgings out of the impressions (knockouts, springs, levers).

Figure 123 shows a die block. Main shoes *1* and *5* accommodate unattached plates *4* and *10* with impression inserts *7* and *8* secured by wedge plates *3*, pressure shoes (tacks) *6* and *9*, and bolts.

Provision is made of one wedge plate for each die and of as many pressure shoes as the number of impressions. The die has guide posts *2* arranged at the side of the die

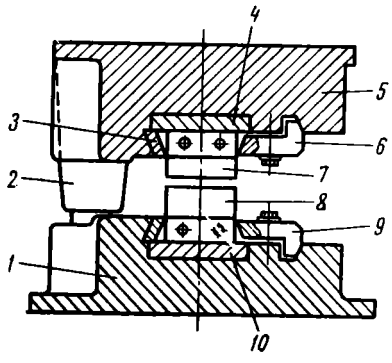


Fig. 123. Sectional die block for crank-type hot forging presses

1—lower shoe; *2*—guide post; *3*—wedge plate; *4*—upper unattached plate; *5*—upper shoe; *6, 9*—tacks; *7, 8*—impression inserts; *10*—lower unattached plate

opposite to the operator. They ensure accurate matching of the impressions in the top and bottom blocks.

The impression inserts can be of prismatic and cylindrical shape.

Friction-press dies. The friction presses employ the dies of four main types:

open dies—for forgings with flash around the parting line (with a one-piece die, with or without a knockout);

closed dies—for flashless forging (with a split die);

closed dies—for extrusion stamping (with a one-piece die and knockout);

closed dies—for making rod-shaped forgings (with a one-piece inclinable die).

The dies used in friction presses are usually of single-impression type. The die consists of two half members: the bottom one which is a female die, and the top one which is a punch.

The female dies can be of solid design or with inserts. As a rule, they have a socket for a knockout. The dies are secured on presses mainly by wedges.

Figure 124 shows a closed die with a one-piece female die and knockout used for flashless stamping on a friction press.

Trimming dies. These are classified into those for hot and cold trimming of flash. They comprise essentially three components: a shoe, a female die, and a punch. Some tools are provided with strippers.

The tools for hot trimming are made to the drawing of a hot forging, i.e., taking into account the expansion of the part when it is hot; the tools for cold trimming

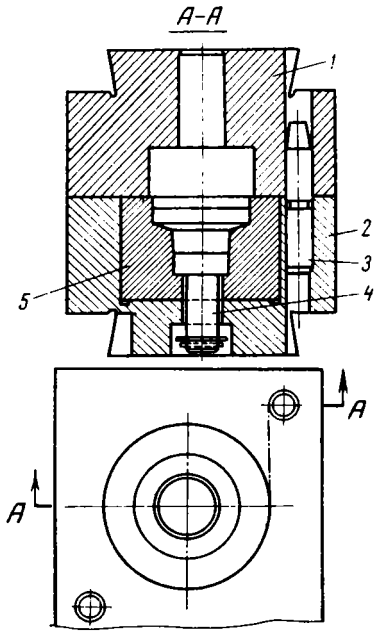


Fig. 124. Closed die for friction press
1—upper striker; *2*—lower striker; *3*—guide post; *4*—knockout; *5*—insert

are made to the drawing of the ready article.

The clearance between the punch and female die in hot-trimming dies is made much larger than in cold-trimming dies, coming up to 2 millimetres per side. The female die port over the trimming shape is made without draft within 5-8 millimetres, beyond which a 5-7° draft is provided to allow an unobstructed drop-through of the trimmed forging.

For longer life of hot-trimming female dies their cutting edges are sometimes hard-faced with hard alloy since conventional dies get very hot during operation and, consequently, wear out rapidly.

The hot-trimming dies have high shoes with a port for removing the trimmed part, the cold-trimming dies being provided with low shoes and a knockout. The female die is attached to the shoe by wedge or screws.

The female dies can be either of one-piece or split design. The split dies are intended for trimming large-size forgings. This saves die steels and facilitates manufacture and repair of female dies.

The sizes of the punch working part are prescribed taking into account the clearance needed for the punch to enter the female die opening. The clearance is provided only at the expense of decreasing the punch sizes. If the clearance is small and the metal cools off quickly, the flash sticks to the punch and is removed by the strippers attached to the lower shoe of the tool.

The strippers are made in the form of plates with an opening for the punch (rigid stripper), spring-loaded plates, as well as in the form of cramps, rubber cushion, etc.

Figure 125*a* shows a hot-trimming die of a simple design.

The trimming dies come in various designs; they may comprise some other components in addition to those described (guide posts, bushings, etc.).

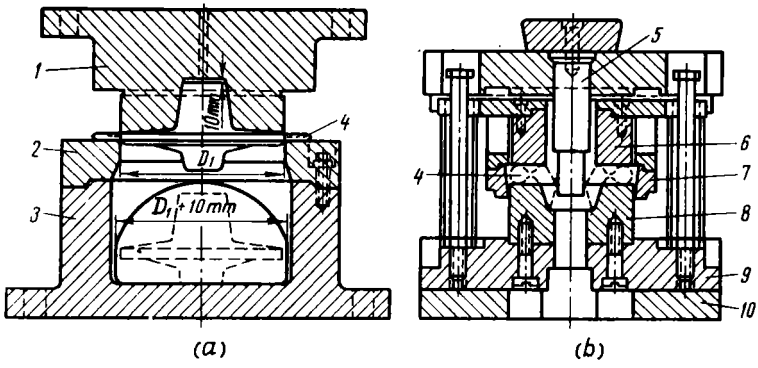


Fig. 125. Trimming dies

(*a*) for hot trimming of flash; (*b*) for cold trimming of flash and piercing of film; *1*, *7*—trimming punches; *2*, *8*—female dies; *3*—shoe; *4*—forging; *5*—piercing punch; *6*—stripper; *9*—lower shoe; *10*—unattached plate

In large-lot production of forgings a wide use is made of combination dies suitable for simultaneous operations of flash trimming and piercing holes in forgings (Fig. 125*b*).

Forging machine dies. The tools, employed for upsetting performed on hot forging machines, comprise essentially four components: punch holder, punch, and two body blocks (RH and LH). The punch holders can be one-piece (Fig. 126*a*) or split (Fig. 126*b*).

The one-piece punch holder has constant spaces between the punch axes. These spaces should be strictly observed when lathe-turning the impressions in female dies. If the spaces between the punch axes have to be changed, the split punch holders are resorted to. Each section of such holder has one punch. When making an assembly of punch holders, provision is made of steel ground plates of the ap-

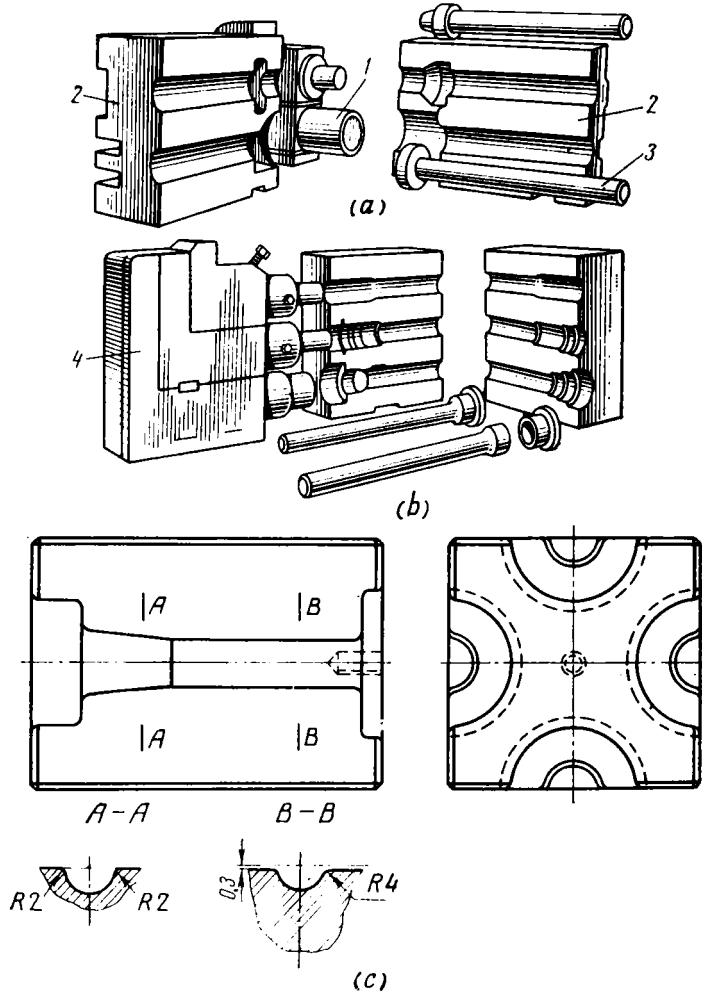


Fig. 126. Punches and female dies for hot forging machines

(*a*) double-impression set; (*b*) triple-impression set with split punch holders; (*c*) female die with impressions on all four sides; *1*—punches; *2*—female dies; *3*—forgings according to operational elements; *4*—split punch holder

propriate thickness varying thereby the spaces between the impression axes.

It is possible to sink from one to six impressions in a female die depending upon the nature of upsetting which, in turn, depends upon the part shape. The body blocks are bolted in the machine, the stationary block being secured to the frame, the movable, to the cross clamping slide. To prevent the die blocks from vertical displacement, they are fastened with keys.

For sparing use of alloy tool steel and lower cost of machining, the female dies are made split or with half-round inserts. To make the best use of material, the die impressions are sometimes made both at the face and the rear sides, or, occasionally, at all four sides of the die blocks (Fig. 126*c*).

The mating faces of the two die blocks have working parts and suitable grooves for gripping the bar stock. To avoid the slipping of the bar during upsetting, the gripping part is lathe turned to be oval. For this purpose, when turning the female die, it is necessary to place two metal plates 0.5-0.6 millimetre thick between the die blocks. When turning the working part of the impression these plates are removed.

For good holding of the bar the length of the gripping part is made equal to three times the diameter of the bar, the surface of this part is left rough (bearing the tool traces) for greater friction.

Chapter 13

Manufacture and Testing of Dies

13.1. General Requirements

To obtain high-quality dies, manufacturers work out specifications for each type of die.

Drop hammer dies are to meet the following general requirements:

1. The maximum deviation from flatness on the machined surfaces of the parting plane, the shank and the refe-

rence corner should be within 0.15 millimetre over the length of 600 millimetres.

2. The support plane of the shank and the parting plane of the die can be out of parallel within 0.08 millimetre over the die length of 300 millimetres.

3. The side surface of the shank and that of the reference corner can be out of parallel within 0.06 millimetre over the length of 300 millimetres.

4. In closed parts of the die the support plane of the shank can be out of parallel within 0.15 millimetre over the length of 300 millimetres.

5. The inclined surfaces of the dovetail-type shank can be out of parallel within 0.06 millimetre over the length of 300 millimetres.

6. Misalignment of key slots in the set should be within 0.6 millimetre.

7. The sides of the reference corner can be mutually non-perpendicular within 0.1 millimetre over the die length of 300 millimetres.

8. The tolerance on a dimension from the front side of the reference corner to the key slot axis should be ± 0.2 millimetre for each die half member, and the combined tolerance for the two die half members should be within ± 0.3 millimetre.

9. The tolerances on dimensions of the finish impression should ensure the manufacture of stamped forgings according to the prescribed accuracy. Depending upon the sizes of the part, the following tolerances can be taken:

For small parts . . . . + 0.1-0.22 mm, — 0.05-0.1 mm;
For medium parts . . . . + 0.2-0.5 mm, — 0.1-0.25 mm;
For large parts . . . . . + 0.3-0.8 mm, — 0.15-0.4 mm.

10. The difference between the sizes of the finish impression shapes in the top and bottom parts of the dies is permitted within 0.1-0.2 millimetre depending on the accuracy of the part. The tolerances on dimension difference in preliminary impressions are twice as much.

11. The above-described tolerances refer to external dimensions of the forgings. The internal dimensions (depressions, slots, recesses) are given the tolerances similar to those for external dimensions but with the opposite sign.

12. The tolerances on vertical dimensions are taken from the parting line. If the vertical dimensions are below the parting line, the tolerances are taken similar to those for external dimensions; if the impression surface projects from the parting line, the tolerances are taken with the opposite sign, as shown in Fig. 127.

13. The dies should be ground over the parting line and the plane of the reference corner.

14. Non-working surfaces of the dies should be machined to Class 5 surface finish.

15. The face and other machined surfaces of the die having no impressions are allowed to bear some nicks, scale traces or some other defects provided they are trimmed away and located not deeper than 0.2 millimetre.

16. No undercuts on the side working surfaces of either finish or preliminary die impressions are allowed.

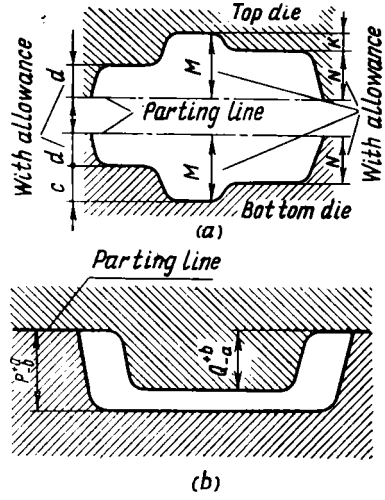


Fig. 127. Tolerances on vertical dimensions of drop hammer die

(*a*) general diagram; (*b*) depending upon the position of working surface of die with respect to parting line

17. The die impressions should be machined to Class 8 surface finish, the abrasive tool lines being lengthwise to the metal flow but not crosswise. The surface of the finish impression should be very carefully polished.

18. No cracks, burnt spots, nicks, partial pockets distorting the impression shape (although such distortions may be within dimensional tolerances) can be tolerated on the die working surfaces.

The dies for crank-type hot-forging presses are to meet the following requirements:

1. The manufacturing tolerances for such dies are somewhat closer than those for drop hammer dies.

2. The dimensions of all the impressions in the inserts should be observed with the same tolerances as those in the drop hammer dies. The surface finish of the impressions should be not worse than in the impressions of drop hammer die.

3. The shapes in the top inserts and those in the bottom ones can mismatch within 0.1 millimetre in the impressions of ordinary accuracy, 0.05 millimetre in the finish impressions of higher accuracy, 0.2 millimetre in the preliminary impressions and 0.5 millimetre in the preparatory impressions.

4. Out-of-parallelism of the support plane for impression inserts and the support plane of the shoe can be tolerated within 0.1 millimetre over the length of 500 millimetres. The tolerances on the diameters of the nests for cylindrical inserts should not be in excess of +0.1 millimetre.

5. The dimensions of the working cylindrical impression inserts should be observed within the tolerances of 0.05 millimetre over the locating diameter. The rest of dimensions of the die components should be observed within the tolerances indicated in the drawings. The surface finish of those components should conform to the drawing specifications.

The specifications for manufacture of trimming dies are as follows:

1. The maximum permissible deviation from flatness of the support plane in the trimming female die of any size is within 0.3 millimetre.

2. The draft in the female die port for a drop-through of forgings should be accurate to $\pm 2°$. The cutting edges of the die should be trimmed very carefully. The width of the shank may vary within +0.2 to +0.3 millimetre. The tolerance on the shank length is $^{+2}_{-1}$ millimetres.

3. Out-of-parallelism of the locating rib of the shank with respect to the longitudinal axis of the working shape in the punch can be tolerated within 0.2 millimetre over the entire length. The maximum permissible deviation from flatness of the support plane of the shank irrespective of its size is 0.2 millimetre.

4. The vertical axis of the punch should be perpendicular with the support plane of the shank. The permissible out-of-perpendicularity is within 0.25 millimetre over 100-mm length of the punch working part.

5. The side surface of the punch and the surface of the working shape in it should be machined to Class 8 surface finish.

6. The sizes of the cutting outline of the trimming female die and the working shape in the trimming punch are machined with an allowance left for individual fitting to the sample forging.

13.2. Selection of Steel Grade

The hot-forging dies operate under very severe conditions. They are subject to repeated impact loads under elevated temperatures dissimilar in different areas of the die. Therefore selection of the steel grade for dies is of much importance.

The steel grades used for making dies should be heat-resistant, possess high resilience, adequate strength, low wear (abrasion) and lend itself well for machining by cutting tools.

The hot-forging dies are made from high-quality alloy tool steels. The presence of molybdenum, in particular, is considered to be especially favourable for the quality of die steel.

Steel grades which have gained the most extensive application in die making practice in the Soviet Union are as follows:

5ХНМ, 5ХГМ, 5ХНВ, 5ХНТ — for drop hammer and for forging dies;

7Х3, 8Х3 — for female dies and punches of hot upsetter dies;

3Х2В8 — for inserts and punches used in horizontal forging machines and forging power presses operating under extremely high temperatures;

Х12, Х12М, 8Х3 — for female dies and punches of hot trimming dies and their inserts.

The simple-shaped dies whose wear-resistance is of minor importance can be made from steels, grades 55, 60, 4ХС, 50Х and some other inexpensive steels.

The components of sectional dies which do not contact the heated

metal being machined are made from structural steels, grades 35, 40, 45, 50, 40X, and 50X.

The guide posts and bushings are made of structural case-hardened steels, grade 20, and the springs, of grades 60Г or 65Г.

Iron-and-steel mills producing die steel deliver die blanks of rectangular and cylindrical shape of standardized sizes, the steel having been fully annealed and hardened to Bhn 187-255.

The die blanks are obtained by smith forging under hammers or in presses. In such processes the ingot is to be upset by not less than 50 per cent of its initial thickness.

Forging reduction ratio is understood herein as the ratio of the cross-sectional area of the upset ingot to the cross-sectional area of the ready die blank. The direction of fibres (i.e., the direction of draw in forging) should be lengthwise to die blanks.

13.3. Manufacturing Process

The following four stages are involved in the making of hot-forging dies:

preparatory stage (making die forgings, patterns of parts to be stamped, templets and other tools; cutting off the die component blanks from bar stock according to the specifications);

rough machining (roughing of forgings, cast and rolled bars on planing, milling, lathe-turning, and other metal-cutting machines; grinding planes and datum surfaces for marking, marking). The roughing is done without marking according to the dimensions indicated in drawings and specifications;

final machining and assembling (finish machining of rough-machined blanks on metal-cutting machines so as to reduce their size and shape to those specified in the drawing; if the workpiece is to be machined further, an allowance should be left; bench fitting, heat treatment, finishing, i.e., grinding and polishing, and assembling);

bringing the die to its working condition (inspecting the die, testing it in a press or under a hammer, checking up whether the stampings are fit, detecting, and remedying the faults).

The die is to be brought to its working condition either by its maker or by the higher-skilled fitter whose only concern is to put the products into good working order. In the latter case the adjusting fitter accepts the die for testing and finishing after it has been accepted by the inspection clerk.

Making die component blanks. The makers of die components use not only bar stock and cold-drawn metal, but extensively employ forgings and steel castings, occasionally welded blanks.

The blanks for the components which are to resist high loads and to do the work of deforming are mostly forged or stamped (for instance, inserts for forging machines). Large-size deforming parts which will receive moderate specific pressures are made from steel castings.

The locating, guiding, fastening, locking, and stripping components are usually made from bar stock.

The cast blanks may be hollow inside, their mass being, consequently, lower than that of bar stock or cast blanks, hence sparing consumption of metal. Besides, time and labour to be consumed on machine and bench work can be saved.

The majority of blanks for deforming components of hot-forging dies comes for machining as forged blocks or block pieces obtained by cutting forged strips.

The forged blanks for top and bottom parts of dies are referred to as blocks. Their sizes are standardized. The smallest block has the following sizes: 200 × 140 × 300 millimetres (width × height × length), the largest: 375 × 350 × 950 millimetres. The blocks of larger or smaller sizes do not comply to standards and can be of any sizes to suit particular conditions. Figure 128 illustrates the sizes of die blocks at the parting plane of the die and the location of shanks taking into account the direction of fibres in blocks.

The direction of the ingot axis in the block is determined by the stamp put by the manufacturer of blocks at the intersection of the edge diagonals perpendicular to the ingot axis. The direction of dimension *A* always coincides with the direction of the ingot axis.

The axis of the shape of the finish impression in the

die should be directed along the ingot axis which contributes to longer life of the impression.

The displacement of the die centre from the middle of the block is allowed within 0.1 the overall size of the block in direction of displacement.

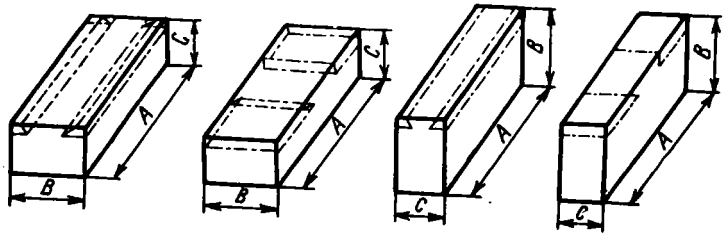


Fig. 128. Die blocks and versions for planing the shank

The forged steel blocks and shaped blanks are given preliminary heat treatment: annealing or normalizing (hardening and high-temperature tempering).

Sequence of manufacture. One-piece drop hammer dies can be manufactured in different operational sequence, depending upon the size of the die, the shape of the working cavity in the finish impression, the required hardness of the die and the available equipment.

Small-size dies of high hardness (Bhn $>$ 350) are manufactured observing the following sequence: drilling holes for hoisting hooks; planing or milling all the surfaces; grinding the surfaces over the parting line; marking; milling the impressions and a sprue for pouring molten metal into the cavity; bench fitting of die impressions and lead cast; milling the depressions for a slide block, preparatory impressions and flash gutters; bench fitting of preparatory impressions; hardening and tempering; finish grinding of parting surfaces and of shanks; final bench finishing of die impressions; inspection.

In making *medium-size dies* with Bhn 320-350, after the holes are drilled, all the surfaces are planed, and the marking is done, all the impressions are rough milled, then the die is hardened and tempered.

The hardened dies are inferior to the cutting tool as far as hardness is concerned. This is why they are finished, as hardened, by cutting on machine tools by the use of sintered-carbide or high-speed tools. Next the impressions are given complete bench fitting and finished with abrasives. Such operational sequence means that the block warping during hardening will not detract from dimensional and geometrical accuracy of die impressions.

The manufacture of *large-size dies* with hardness of Bhn = 320 (which is considerably lower than the hardness of the cutting tool) is begun with hardening and tempering of the block which is followed by machining and bench fitting. No secondary hardening is done.

13.4. Machining of Die Components

Time consumption on machining the surfaces and other elements of the die amounts up to 25-40 per cent, on machining of die impressions up to 40-50 per cent, and on bench fitting and assembling up to 35-10 per cent.

Machining of drop hammer dies. The manufacturing proces of machining the drop hammer dies involves the following operations:

1. Trimming a flat for a brand on a grinding-and-roughing machine and branding the blank.
2. Drilling holes for hoist hooks to the marking on a radial drilling machine.
3. Matching and planing the two die parts (parting surfaces, sides, shanks, slots for brands, etc.).
4. Sinking the impressions (if the impressions are of simple shape they are sunk on vertical milling machines to the marking, those of intricate shape are machined on die sinkers).
5. Sinking the preparatory impressions.
6. Sinking the recesses for a sprue (a reduced part of the forging for its convenient gripping by the tongs) and the grooves for lead cast, as well as the flash gutters around the finish impression.
7. Combined planing of the half members of the reference corner in the die (if required after the finishing bench fitting of the die impressions and check up).

8. Grinding the parting surface and the support surface of the shank on the surface grinding machine, this is done after heat treatment to eliminate warps.

9. Milling key nests and chamfers on their edges on the vertical milling machine to the marking.

In the dies with locks and counter-locks, as well as in those with the flat parting surface, additional planing and milling operations are performed upon the shaped surfaces of the die to the marking, this being done after the slots are branded.

Machining of dies used for such forgings as rings, discs, and bushings (round at the parting plane). These dies are more simple to machine: after the centres are marked, the die half member is machined on a surfacing or vertical lathe.

The combined planing of the two die half members is carried out in the following order:

planing the side of the reference corner and of the parting surface;

marking the shank to the drawing and to the templets, planing the shanks and the areas where the shanks change into shoulders;

planing the front of the reference corner and the slot for the die brand which is on the front and spaced 20-30 millimetres from the shank shoulders;

checking whether the planing is done properly: parallelism of the parting surface and the shank support plane; parallelism of the inclined sides of the shank to each other and to the side of the reference corner; matching of the axes and the sides of the shanks, longitudinal and front sides of the reference corners in the top and bottom parts of the die; correctness of the right reference corner and the right angles between the parting surface and the sides of the reference corner; correctness of sizes and smoothness of change from the sides of the shank to the shoulders (to be checked by a templet);

branding the steel grade, the part number, the die drawing number, the die index in the brand slot.

If the die has locks, after planing they are marked and planed on a shaper or milled to the marking on a vertical milling machine.

The planed and milled locks are fitted by a benchman till the locks match completely and the collision surfaces of the top and bottom parts of the die tightly contact (provided the two parts are accurately mounted to the reference corner).

Next the die impressions are marked by marking-off tools according to the drawing and by the use of the templet. When marking, the parting surface is plotted not only with the outline of impressions, axial and auxiliary lines but also all the lines of intersection of the parting surface and the surfaces of internal outlines (even if such outlines stop short of the parting surface). To decrease the mismatching of the shapes of the top and bottom half members of the die, they are marked simultaneously, transferring immediately each dimension from one half member to the other.

The die impressions of simple shape in small- and medium-size dies are sunk on vertical milling machines, those of complex shape in medium-size dies, as well as all the impressions in large dies, are sunk on die sinkers.

The sinking on the vertical milling machines is performed in two operational passes. First rough sinking with an allowance of 1.5-2 millimetres (starting from the deepest section of the impression) is performed, then follows the finishing operation. The latter is performed by means of taper mills having a taper equal to the die draft and the face radius equal to the corner radius of the transition from the bottom to the side of impression (according to the drawing). The side angles in the impression cavity are machined with the same mills but of smaller diameter and having their faces completely rounded off.

After the deepest section of the impression has been sunk, the remaining areas are machined by the same method. For bench fitting an allowance is left of 0.3-0.5 millimetre over horizontal dimensions, while the vertical dimensions of the die are taken by 0.2-0.3 millimetre greater than indicated in the drawing. This provides for an allowance at the side of the parting surface for finish grinding after hardening and, to a large extent, obviates the need of further deepening of the impressions (they are to be deepened due to the warping of the die). Whether the impres-

sions have been properly sunk is verified by the profile templets.

The preparatory impression should be sunk after the finish one has been sunk and checked up. In the preparatory impressions, first the outline is milled which passes along the axis of the future article, this outline is sunk to the full depth of the appropriate templet, then the cross sections are machined to the cross outline templets and all the projections and irregularities are milled away.

The recesses for sprues, grooves for the lead cast in the die impression and the flash gutters are milled by the end mill with the face of the required shape.

After bench fitting of the impressions and heat treatment of the die the warpings on it are to be corrected. For this purpose, the support plane of the shanks and the parting surface are ground on the surface grinding machine, simultaneously making the impression die as deep as required.

Machining of components of the trimming dies. When making hot- and cold-trimming dies it is a standard practice to use forged blanks. The machining of punches having a dovetail-shaped shanks is begun with the planing of the face (bottom) surface on a shaper, then, the shank (support) and front surfaces are machined. The fitter on marking-off operator marks the shape of the shank on the front surface and transfers its axis on the face of the punch. This axis is taken as a reference for marking the cutting outline of the punch and its shape on the front surface.

The punch shank is machined to the marking on the planing machine and, then, its cutting outline is milled on the vertical milling machine, with the punch clamped in the vice having shaped jaws answering for the shape of the shank.

Whether the machining has been done properly is verified by the templet, having the size and shape of the punch plus clearance to be left between the punch and female die, and bench-fitting allowance.

Cylindrical trimming and piercing punches are machined on lathes, their shanks being machined on the shapers.

The female dies for trimming dies are made by the same methods as applied for making female dies of blanking pressworking dies (see Ch. 9). An example of manufacturing process involved in machining the trimming female

dies is offered by the machining of a two-section die secured in the shoe by the use of a wedge. A pair of prismatic forged blanks for the female die are planed as one piece from six sides to an angle of 90°. Then the holes are drilled to a jig and reamed for a coupling pin. When doing so it is necessary to take into account that the coupling pin is set in one section by the push fit and in the other by the slide fit.

After the section is set on the pin, and the cutting outline and the land around it are marked, the side bevels are planed with a taper for a socket in the shoe, and the steps round the land are rough planed. Then, following the cutting outline the port in the die is slotted and a draft for forgings to drop through is made with a bench-fitting allowance of 0.2-0.3 millimetre on the cutting edge.

The die port slotted, the steps round the land and the recesses for the sprue are finish milled. Next, the female die blank is set to the benchman who gives bench fitting to the cutting outline and fits it to the sample forging (casting) of the part.

After the sections are heat treated, the land round the trimming outline and the support plane of the female die assembly are to be ground.

13.5. Making and Using of Templets

The die impressions are machined to the contour marked on the parting surface and using the templets for checking the dimensions and the shape of the depressions. Figure 129 shows the diagram of the bottom half member of the drop hammer die and a set of templets for checking all the sections of the cavity marked on its face.

Makers of hot forging dies use the following types of templets: general, lock, outline, profile, and auxiliary.

General templets are intended for repeated use in making any dies for measuring the shanks, slide block sockets, key slots, die drafts, fillets and corner radii, and other standardized elements of dies.

Lock templets serve for fitting the locks during their machining; they are also used as auxiliary templets for marking of impressions.

Outline templets are templets showing contour only.

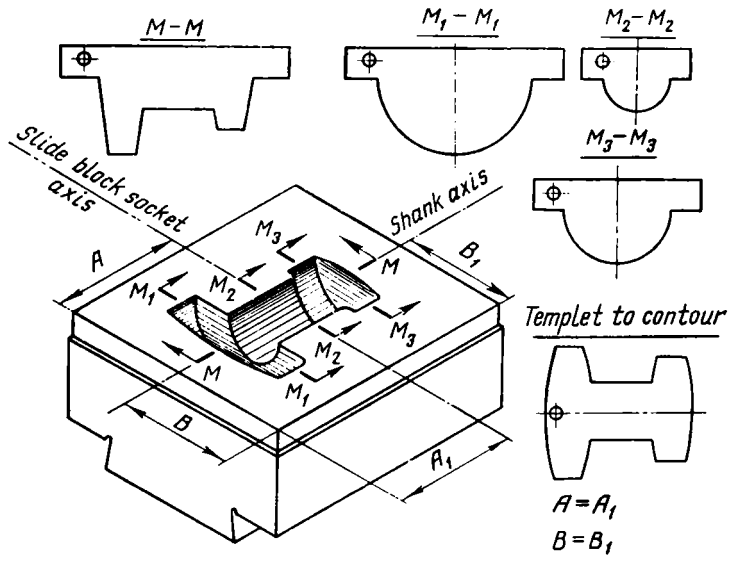


Fig. 129. Bottom half member of drop hammer die and templets for checking cavity of its impression during manufacture

They are the exact replicas of the impression outline on the die parting plane. These templets are used for marking the die half members, checking the sunk impression and final checking of the impression outline in the ready die; they are also used for checking hot trimming female dies and for sinking the outlines of female dies and punches on die sinkers. Besides the impression outline these templets are sometimes given individual lines for its areas and also the lines corresponding to the internal corners of the die impressions which result from intersections of different curved surfaces and planes of the figure.

Profile templets serve for taking measurements of die impressions during their sinking or additional bench fitting.

Auxiliary templets are used as supplementary tools for outline and profile templets in the manufacture of complex die impressions, especially if the section of the forging body varies with changes in its length.

The templets are made from steel sheets, occasionally from 1-3-millimetre duralumin sheets. The templets for single-time usage (marking-off, lathe turning, profile) and those requiring no accurate finish are made from non-hardened steel with 0.6-0.8 per cent carbon. The high-precision templets and frequently used ones (general purpose, outline, and profile) are heat-treated with subsequent grinding and finishing.

To make a precision templet, first a counter templet is used to which the complex areas of the templet are machined, the form mills are sharpened and the used templets are checked after the die is made. When working to the marking on a vertical milling machine, the templet is used for marking-off purposes, and the counter templet for milling, for instance, a bender or a lock. It is impossible to make a symmetrical templet without resorting to a counter templet; no complex profiles should be made by eye.

The working surfaces of all templets must be smooth and have gradual transitions within the prescribed tolerance The tolerances on templets are taken from the approved standards.

13.6. Bench Fitting of Dies

The benchman deals with the sunk impressions imparting them the final shape and sizes conforming to the drawing. During bench fitting the benchman trims away the crests and lines from the die impressions formed due to milling. He also corrects the faults caused by previous operations. The impressions are checked not only by measuring tools and templets, but also by lead cast.

The lead cast removed from the die displays the matching of the working surfaces as well as all the errors due to faulty marking or milling. If the main cavities match but only some areas of minor importance slightly depart from the prescribed shape, the benchman has to remedy the defects.

To obtain the casting of the impressions in a small die, the half members of dies are mounted, with their rear portion, on the cast-iron plate. They are held together in this position by means of several screw clamps or chain ties,

levelled to the reference corner and cast with low-melting metal alloy, quick-setting plastics, or molten mixture of sodium and potassium nitrates (two parts $NaNO_3$ and one part KNO_3). Prior to casting, the die impressions should be thoroughly cleaned. When casting with metal, the impressions are coated with dry chalk, when casting with plastics they are coated with parting compound.

After the cast metal or other composition sets, the die half members are separated from each other and the casting is carefully removed to avoid damaging it. The flash is filed off the casting and it is measured over all its parameters specified in the drawing. The faults in the die are remedied by bench fitting the smaller sizes to the larger ones within the permissible deviations. With considerable deviations (for instance, with unilateral displacement of figures) the half members of the die are so displaced with respect to each other as to obtain the correct casting. Then the planing (or milling) machine is employed to match the die members, to plane the reference corner to the marking (or with the aid of the correct casting placed beforehand into the impression).

Planing is also used for making the shank sides and the side of the reference corner parallel. Further bench fitting is expected to bring the dimensions of the impressions and their surface finish to the state specified in the drawings. The dimensions are checked by universal measuring tools and templets. The casting, of saltpetre is not suitable for checking the dimensions, since it shrinks when cooling by 0.8-1.2 per cent depending on the shape of the cavity.

To avoid misalignment during bench fitting of the die, the contour templet and the "bottom" templet (also called "grate") are plotted with axial lines which must be in the vertical plane common with the die axis.

The bench fitting of dies is performed by hand pneumatic or electric tools provided with rotary files or abrasive heads. For rough grinding use is made of ceramic- or bakelite-bonded abrasive tools with grain size of 40-25.

Finish grinding is done by vulcanite-bonded abrasive tools with grain size of 16-12.

Polishing is carried out with the aid of flexible buffing tools: felt wheels whose edges are impregnated with abrasive

grains of corresponding grain size (see Ch. 2, para 6), fibre or wooden polishing tips with paste.

To clean the impressions off the remaining abrasive and dust, hair tips or round brushes are used.

The methods involved in bench fitting of dies are various, but some of the die elements are of similar design differing only in sizes and, consequently, are machined by similar methods.

Bench fitting of dies is usually begun with the deepest areas of the impressions, i.e., those which take the form of projections, heads, excessive stock, and other bossy parts on the stamped forgings. The nests and projections are first fitted to the profile templets at certain cross sections. Then the surfaces which are between the sections are fitted to the straight edge and checked up for clearance. The nests are checked for their correct depth by the "bottom" templets and depth gauge; the position of nests and projections is verified by the contour templet with the centre lines plotted on it. All the templets are located resting against the parting surface or lock shoulders.

The die impressions should have no sharp corners, and, consequently, all of them are rounded off as specified in the drawing. If it was impossible to round off the corners during the milling process, the sharp corners should be chipped by a chisel, then filed off by a file, and ground away by hand abrasive tools imparting them the curvature of the prescribed radius. The fillets and corner radii are verified by the templets.

Whether the corners are properly rounded off is of much importance, hence the job should be done carefully. Special attention should be paid to the areas where the impression edge changes its direction abruptly; at the corner of this change the fillet should be carefully rounded off and polished. The flash lands are also to be grounded away, eliminating, thus, scores and lines due to milling, which may hinder the flow of metal into the flash gutter cavity.

After the impressions and flush gutters in the two half members of the die are fitted with respect to depth, contour, and all changes of their outline and finished, another lead cast is performed or a mould taken of the die impression. If the shape and size of the mould correspond to the

drawing of a hot forging, it is possible to pass over to the final operations of die making, those of grinding and polishing the impressions.

From the bench the die is handed over for being heat-treated: hardened and tempered. After the die is hardened its size somewhat increases or decreases, depending upon the grade of steel, the size of die, the shape of impressions, as well as heat-treatment conditions.

The fitter should know the grade of steel of which the die is made, its physical and manufacturing properties, and how they change under heat treatment. When machining the impressions and allowing for possible changes in dimensions, the fitter is to leave the necessary allowances for finishing the hardened dies (0.1-0.2 millimetre in small dies).

The dies are finished with abrasive tools using hand pneumatic or electric tools. The finished die is submitted to inspection.

After the die is inspected and accepted from the fitter, the die is tested by trial stamping of several forgings on a hammer or in a press (depending upon the purpose of the die). If the verified dimensions and geometrical forms of the cooled forging comply to those specified by the drawing, the die is considered fit. If, on the contrary, the trial stamping is unsatisfactory, the die is returned to the fitter to be additionally finished.

Chapter 14

Repair of Forging Dies

14.1. General

The expenditures involved in manufacture, maintenance, and repair of hot-forging dies comprise a considerable proportion of prime cost of forgings (20 per cent and over). Reasonable employment of dies, the proper care of them, timely and good repair can reduce the prime costs of the products released from the hot-forging shop.

The drop hammer and hot-forging dies are the pieces of

tooling which are subject to rapid wear. Sparing consumption of dies can be achieved by improvements in their design, application of wear-resistant steels, advanced manufacturing methods, prolonging the life of dies, timely and high-quality repairs.

If the dies are expected to render good service, the following requirements are to be met with: good working condition of the hammers and presses (especially of their guides and the places where the dies are mounted), proper storage of dies and due preparation of them for work, correct mounting of dies and their reliable attachment, good cooling and lubrication of die impressions during stamping, timely and careful removal of scaling due to the preceding operations, careful removal of scaling from the die impressions, continuous check up of the condition of dies, the proper accounting of the work performed by dies.

Each die is given a certificate which indicates the purpose of the die, the date of its manufacture, the basic dimensions of die blocks, the grade of steel, the heat treatment cycle, the place, time, and maintenance conditions, where it is stored, the number of forgings made by the die, the causes of failure, etc.

In the course of time the certificate is filled in with entries informing on its work, wear resistance, the number of repairs done and their nature.

To prolong the life of dies, the worn impressions can be reconditioned by hard-facing; another means is to improve the manufacturing process; an electrospark method is resorted to for machining the die impressions making thereby their wear resistance twice as high as compared to the dies produced by conventional machining and bench fitting; use is made of inserts obtained by hot or cold extrusion, which increases their wear resistance several fold as compared to those dealt with on metal-cutting machines.

To increase the wear resistance of dies, their design can be improved by reinforcement of components subject to rapid wear, the die drafts and fillets and corner radii can be varied, the knockouts and strippers are provided, the impressions can be increased in number or their shape be changed, more exacting demands are extended to the quality of impression finish.

To cut down the time of repair, a good practice is to have in supply a spare set of components subject to rapid wear (such as shaping inserts), which are made simultaneously with the basic set. When testing the ready die, a set of spare components is also tested and submitted along with other ready products.

When the dies get worn, they are repaired. There are two kinds of repair: overhaul and maintenance repair. Depending on how frequently the die components get worn and reconditioned, they can be classified into permanent and changeable.

Permanent components are those whose wear spells a complete disrepair of the tool (such as top and bottom die blocks).

Changeable components are those which can be replaced by new ones when worn. If such a component is replaced, the die continues to be operative.

The permanent components are manufactured and repaired in single pieces or in a batch if there are several dies of the same type. The changeable components are always made in a batch or in a lot. In this connection, when designing a die it is necessary to decide upon which components of this particular die will rank among permanent and which among changeable ones. The repairman will proceed from this when selecting the blanks, semi-finished pieces, templets, and devices specially intended for these components.

The repair of hot-forging dies consists in most cases in restoring the proper shape and size of the impressions. During work, as a result of dynamic loads and heat effects from the red-hot blanks the dies heat up. The hot metal of the blank deforms and flows over the die impressions, wearing them out. The properly designed and well manufactured die is expected to operate without repair for a certain period of time yielding the planned quantity of forgings. Some defects can often be detected in the operation of a die although the latter has worked far from long time, one such defect being the sticking of forgings in the die impression. If the operator goes on using such a tool, the time may come when the forging will be impossible to remove from the die altogether.

Some sections of dies are subject to most severe wear,

These are the projections of the impressions, mainly the narrow ones (ribs, bosses) and edge corners. A usual change in the die impressions proceeds as follows. The sizes of the vertical walls are influenced by lateral forces P

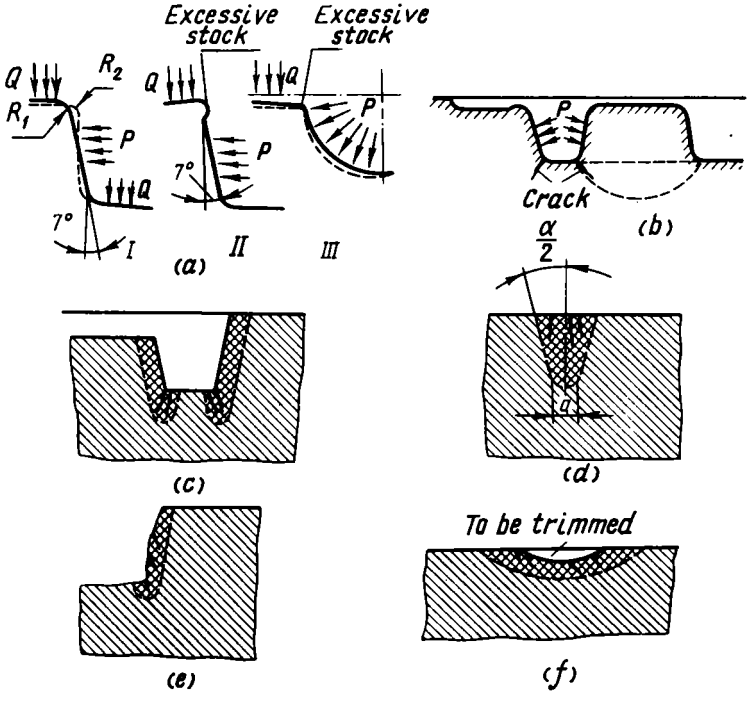


Fig. 130. Defects in die impressions and diagrams showing how to trim faulty spots for hard-facing

(Fig. 130*a*) and as a result widen, whereas the horizontal areas are influenced by the vertical forces Q and are subject to cold working and spread to the sides, i.e., to those directions where they encounter the least resistance.

In operation, where the impression passes over into the flash gutter, i.e., in the place with the corresponding corner radius R_1 (diagram *I*), the latter decreases and a mush-

roomed excessive stock (diagram *II*) forms clamping the forging in the die.

This excessive stock forms the quicker, the smaller the corner radius R_1 on the new die, and the smaller the draft. From this standpoint it is reasonable to increase the draft and provide an enlarged radius of the external corner in the die. However, such an enlargement cannot proceed infinitely but, on the contrary, has a limit which cannot be passed over. With a draft over 7° the part shape will be distorted while the metal consumption will grow, the increase of the corner radius making the operation of a trimming die more difficult and leading to the warps in the part being trimmed.

The dies whose impressions are in the form of a horizontal cylindrical nest (diagram *III*) are of better wear resistance. The walls of such an impression are of higher resistance against the forces P, the excessive stock forms very slowly. This is why such dies serve longer.

One of the most frequent faults consists in flash being too thick (on the flash gutter land) which makes it difficult to go on with trimming the flash. This thick flash is caused by the fact that the die metal receiving the vertical forces experiences, in this area, higher loads. The friction forces arising in the metal flowing under high pressure lead to abrasion of forgings.

The impression bottom is worn least because in this area the vertical forces exert no influence except for cold working of the die metal which increases its wear resistance.

The cracks are most hazardous in the fillets of the impressions. They are caused by nonuniform heating of some areas in the die impression when the blank is heated, and by vertical forces during stamping. The cracks occur most often where the impression bottom has rounded off areas of a small radius. Therefore the fillets and corner radii in such areas should be large enough.

If the die block was insufficiently forged through, the metal mass will have loose (uncompacted) places. During operation of the die the impressions in such places may "sag" which damages the die.

14.2. Types of Repair

The *maintenance repair* is aimed at eliminating the wear of the impressions and other components of the die. When repairing the die the impressions are given their correct size and shape again, the excessive stock on the external roundings is removed, the cavity walls are imparted the correct shape to substitute for the concave one resulting from the die operation, the lines on the flash gutter land are trimmed away, the cracks are caulked away.

Minor repair can be performed in place, i.e., without removing the die from the hammer or press. Such repair is resorted to when the forgings begin sticking in the die or when the recesses in the forgings are distorted. This is a signal of the presence of excessive stock, scores, dents or of crumpled areas of the impressions due to excessive heating.

In the maintenance repair of dies the difficulties consist, among other things, in the hardening of the die material due to cold working of die impressions and their hardening by cooling liquids in the process of hot stamping. The cold-worked spots on the die impressions are treated with abrasive wheels mounted in the portable grinding machines.

The walls and ribs are corrected by a thin vulcanite-bonded abrasive wheel, and by small shaped abrasive heads and specially bent files when dealing with difficult-of-access areas. The corner radii are fitted to radius templets. The flash gutter land is corrected by grinding with the aid of a grinding wheel and emery cloth.

When trimming the impressions one should not remove too much stock so as not to change the forging dimensions after repair to a greater extent than allowed by tolerances. It is very important that, when trimming the impressions, the lines left by the abrasives be of the same direction as the metal flow during stamping.

The cracks are usually caulked with red copper. For this purpose a piece of red copper wire of the required diameter is applied to the crack to be repaired and caulked away by a caulker or blunted chisel. Caulking will neither eliminate the cracks, nor preclude the destruction of the die, but it prevents the forgings from being stuck in the

die and from developing the crack marks in the form of ragged projections.

The maintenance repair also involves replacement of broken or worn changeable components.

Depending on the nature of defects the minor repair of the die impressions can be carried out several times (up to five times) before the die may call for an overhaul.

The *overhaul* is to be assigned when the impressions display a considerable wear. The die is removed from the press and delivered to the tool shop.

The die operation results in increased impressions while repairs tend to their further distortion. Therefore, when the impression dimensions exceed the dimensional tolerances for a forging, the impression is to be completely reconditioned. Reconditioning of impressions and alterations involved comprise what is known an overhaul.

The die is handed over for annealing. The annealed die half members are planed over the parting planes to the depth which will allow marking for further machining, bench, and heat treatment operations performed as if making a new die.

If the die bears any cracks, this should be also taken into consideration, and the parting surfaces planed to such a depth as to eliminate the cracks.

In this way all the die impressions are reconditioned and the shank is corrected by its planing or milling and grinding; the same is done to the reference corners and depressions for the slide block.

Reconditioning of dies by renewing the impressions mechanically sinking them deeper in the die body means unsparing consumption of die steel. For spare use of die blocks (especially for medium- and large-size dies) and better wear-resistance of dies, many manufacturers recondition the worn dies by hard-facing the impressions.

If the die has been made by the method of electrosparking, the electrode tool is preserved and used later on for deepening the impression as required after the parting surface has been planed, next follows the bench finishing.

The overhaul of sectional dies for hot presses and forging machines involves replacement of changeable components: impression inserts, punches, unattached plates, and

worn fasteners. It may also involve straightening the surfaces of female dies, punches, punch holders or cases holding the changeable components.

When carrying out the repair or reconditioning the dies, it is necessary to use the specifications and drawings made up for their manufacture, since the dimensions and quality of repaired dies should not differ from those of new tools. This is especially important in repair of sectional dies the dimensional tolerances on which are very exacting.

14.3. Hard-Facing of Dies

Two methods are known for hard-facing drop hammer dies: arc hard-facing by the use of high-quality electrodes and hydrogen hard-facing by the use of uniform metal, the arc hard-facing being most popular.

The arc hard-facing of dies is carried out with the aid of different types of electrodes having a diameter from 4 to 7 millimetres, and being from 300 to 500 millimetres in length. The metal hard-faced with electrodes is as hard as Bhn = 385-390.

The dies to be hard-faced are annealed, their faulty spots trimmed, the cracks milled away, and the chamfers for hard-facing are made in the impressions. If the impression is of a cylindrical shape, it is to be lathe turned in the direction of the crack until the defect is fully remedied, as shown in Fig. 130*c*.

In some cases the faulty spot can be milled (Fig. 130 *d*, *e*) or, occasionally, merely trimmed by abrasive tools avoiding abrupt transitions (Fig. 130*f*). All the chamfers and grooves, no matter in what way they were treated, should have the roundings with the radius at least $R = 3$ millimetres. The rib sides should be at an angle α as large as possible (not smaller than $\alpha = 40°$), the bottom width should be not less than 9 millimetres (see Fig. 130*d*).

The dies made from chrome-nickel steel and prepared for hard-facing are first heated to 350-400°C to avoid cracking due to heating in the process of hard-facing.

The hard-facing consists in applying individual beads with the electrode being necessarily vertical to the surface being hard-faced. The process is carried out so as to en-

close the arc column as tightly as possible with slag and vapours coming into the weld-area when the electrode coating melts. If the electrode is inclined, the coating will melt unevenly, the protection of the hard-faced layer will be nonuniform which leads to its oxidation and porosity of the seam.

The faulty spots are hard-faced by applying the seams step by step. The previous seam should be trimmed away otherwise hard-facing will be applied onto slag and the deposit will be spoiled. To relieve internal stresses and to compact the deposited metal the seam should be forged by caulking or pneumatic hammers if the seam is large.

To avoid cracking, the die reconditioned by hard-facing is subjected to high-temperature tempering under the temperature of 550-600°C, it is held under this temperature during two hours and then allowed to cool down to 300°C in the furnace. The reconditioned die tempered in this way should be carefully inspected, the deposit tested for hardness, and the die handed over to undergo machining, bench fitting, and hardening. The blisters detected during machining and loose spots in the hard-faced area should be trimmed and welded up again.

The dies hard-faced by the use of electrodes are very hard (R_C 48-58), this is why they are always machined by abrasive tools. Before acceptance of the reconditioned dies they are examined through the five-fold magnifying glass, the hardness of the machined surfaces tested with the aid of portable devices, the shape and size being checked up by means of a lead cast.

Section IV

MOULDS

Chapter 15

Fundamentals of Plastics

15.1. Properties of Plastics

Plastics is a term applied to compositions consisting of a mixture of high-molecular compounds (polymers) and fillers, plasticizers, hardeners, stains and pigments, lubricating and other substances.

The filler governs mechanical properties and influences physical, dielectric, and some other properties. The fillers can be of mineral type, such as crushed mica, quartz, glass fibre, or of organic origin, such as wood flour, cotton fibre.

The plasticizer imparts the plastics higher plasticity and makes it easier to process it into products. The hardeners speed up the process of polymerization and the hardening of plastics.

Some of the plastics can contain nothing but resin (for instance, polyethylene, polystyrene).

Plastics possess the following valuable properties which gain them a wide range of application in industry:

low specific gravity (from 0.9 to 1.8 g/cu cm);

high corrosion resistance;

good dielectric properties when used under d.c. and a.c. (some grades of plastics are indispensable high-frequency dielectrics);

high mechanical properties;

antifriction properties; the friction coefficient of many plastics is very low which allows their employment as material for bearings and slide-bearing units substituting, thus, for expensive antifriction alloys (babbits, tin bronze);

thermo-insulating properties; plastics are poor heat conductors and find wide application as thermo-insulating materials.

Plastics lend themselves well to the most advanced processing methods which allow mass production to be based on comprehensive mechanization and automation of manufacturing processes.

Plastic substances are divided into two principal classes: *thermoplastic materials* which soften under heat and reharden when the heat is removed (these include polystyrene, polyethylene, capron) and *thermosetting plastics* which harden or cure by the application of heat; further heating has no softening effect on it.

15.2. Methods for Processing of Plastics

Processing of thermosetting plastics is based on their capacity of becoming plastic, on being heated for some time, after which they harden irreversibly.

To make an article, the thermosetting material is charged into a hot mould and subjected to pressure. The heated plastics under pressure develops temporal plasticity owing to which it flows filling the working cavity of the mould corresponding to the shape of the future product. In a certain period of time the material hardens and the ready product is removed from the mould.

To press the thermosetting plastics it is necessary to develop the specific pressure of 30 to 100 megapascals depending on the grade of plastics and the design of the mould.

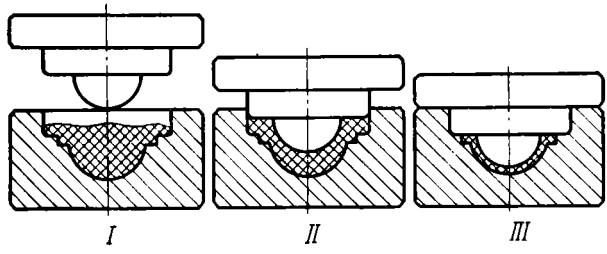


Fig. 131. Processing diagrams of thermosetting plastics by moulding
I—prior to moulding; *II*—moulding begins; *III*—moulding is over

The curing time in the mould to make the material set depends on the thickness of the product walls and varies from 30 seconds to 2 minutes per 1 millimetre of the thickness of the product wall. The processing diagrams of thermosetting materials by moulding are shown in Fig. 131.

The thermoplastic materials are mostly processed by injection moulding in cold moulds on injection machines. This method is essentially as follows. The material is pre-heated outside the mould till it acquires necessary plasticity or fluidity and then injected under high pressure (up to 200 megapascals) into the working cavity of the mould. The material fills in the mould taking the shape of the product. The article cools off rapidly and sets, after which it is withdrawn from the mould, and the sprues and flash are removed.

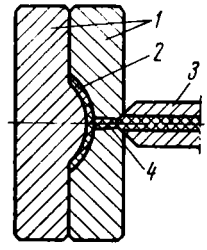


Fig. 132. Processing diagram of thermoplastic materials by injection moulding
1—mould; *2*—article; *3*—nozzle of injection machine; *4*—sprue

The curing time in the process of injection moulding is shorter than in the processing of thermoplastic materials. The cycle of making products on an injection machine lasts but several seconds. Figure 132 is a processing diagram of thermoplastic materials by injection moulding.

15.3. Basic Types of Equipment for Making Plastic Products

Thermosetting materials are moulded in *vertical hydraulic presses*. The operational diagram of such a press is shown in Fig. 133.

Ram *1* travels in cylinder *2* of the pump, displaces the fluid through pipe *9* into working cylinder *8* of the press lifting main ram *7*. When ram *1* descends, only delivery valve *10* is open and the fluid is delivered through pipe *9*. During the reverse stroke valve *10* shuts while inlet valve *3* opens, and a new portion of fluid is delivered through pipe *1* from tank *5* to cylinder *2*. With every subsequent descend of ram *1* main ram *7* of the press will rise. To make this

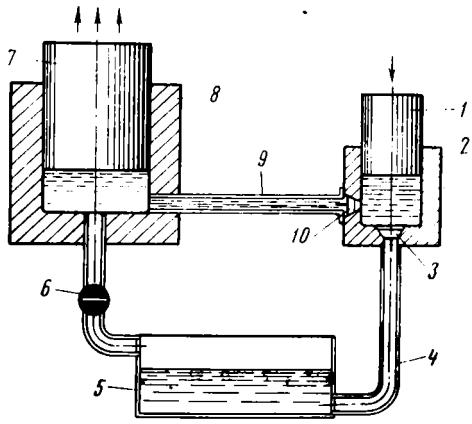


Fig. 133. Hydraulic press for plastics

1—pump ram; *2*—pump cylinder; *3*—inlet valve; *4*—inlet pipe; *5*—tank; *6*—cock; *7*—main ram; *8*—working cylinder; *9*—delivery pipe; *10*—delivery valve

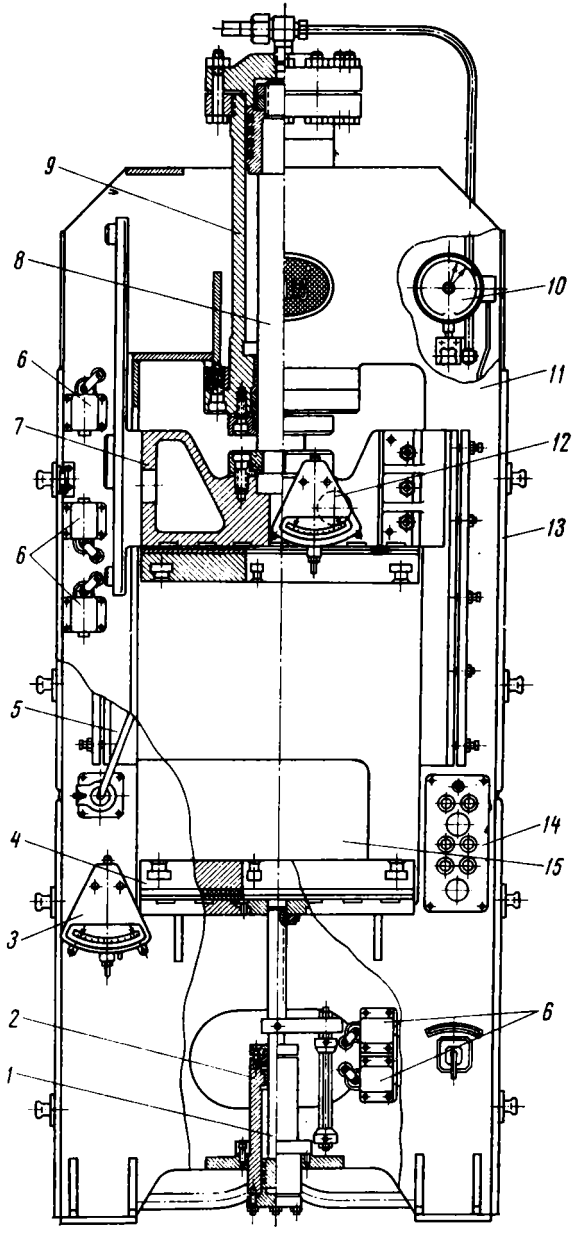
ram descend it is necessary to open cock *6*. The specific pressure of the fluid in the hydraulic system of the pr- is measured by the pressure gauge. Machine oil is used in the hydraulic presses as a working fluid.

The press is normally provided with two pumps: a high-pressure pump and a low-pressure pump. The high-pressure pump (20-30 megapascals) is used only during the moulding of articles. For idle strokes of the ram, the low-pressure pump (600-1500 kilopascals) is used, sparing thus the power consumed.

The hydraulic presses for processing the plastic materials are available with one upper working cylinder (downward pressure); with one lower working cylinder (upward pressure); with two working cylinders (downward and upward pressure, or downward and lateral pressure).

Fig. 134. Semi-automatic press for moulding of plastics

1—ejection ram; *2*—ejection cylinder; *3*, *12*—mould temperature control devices; *4*—bed; *5*—guides; *6*—limit switches; *7*—movable platen; *8*—working ram; *9*—main cylinder; *10*—pressure gauge; *11*—welded frame; *13*—covers; *14*—control board; *15*—hydraulic drive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The presses are operated by either a self-contained unit, or power is provided through a centrally located hydraulic accumulator. In the former case each press is equipped with a hydraulic pump driven by an electric motor. The centrally located accumulator is a pump unit servicing several presses.

When operating the press, the operator controls the motions of the ram. The ram carries the movable platen which accommodates the top of the mould. The stationary bottom part of the mould is mounted on the press bed. A standard moulding operation comprises the clamping of the mould, holding under pressure, and ejection of the moulded article.

The modern presses are provided with the means to change from one operational element to another automatically. The operator is concerned merely with charging the material into the mould and pushing the button for setting the press into operation. A general view of a semi-automatic press with a self-contained motor is shown in Fig. 134.

The main units of the press are mounted on welded frame *11*. Movable platen *7* is moved by ram *8* over guides *5*. The electric devices for controlling the press and heating the mould are accommodated in the recesses of the columns and closed by covers *13*.

The adjustable cams and limit switches *6* are used for adjusting the stroke of working ram *8* and ejection ram *1* of the press. Individual hydraulic drive *15* is arranged behind the press.

As already mentioned the products made from thermoplastic materials are produced by injection moulding on *injection machines* (Fig. 135).

The raw material charged in hopper *1* is batched in device *2* for one moulding, then it is supplied to delivery chamber *3*. By the stroke of piston *4* the material is delivered into heating cylinder *5* with electric heater *6* where it is softened (melted). The heating cylinder provides a room for material sufficient for 8-10 mouldings. When the piston delivers the next batch into the heating cylinder, the same amount of already-melted mass is squeezed through the nozzle of the injection machine and sprue channels of mould *7* into the shaping cavity. The mould consisting of two main parts—the front and the rear ones—is cooled by water flowing through channels *8*.

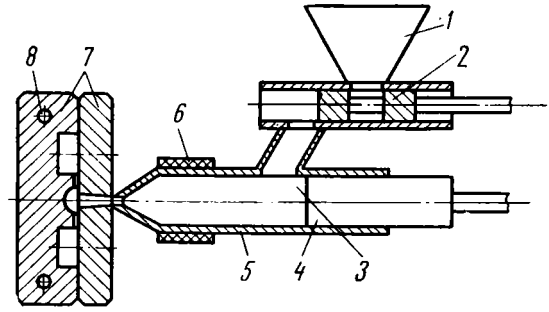


Fig. 135. Injection moulding of thermoplastics
1—hopper; *2*—batching device; *3*—delivery chamber; *4*—piston; *5*—cylinder; *6*—electric heater; *7*—mould; *8*—cooling channels

Figure 136 shows a general view of the automatic injection machine (thermoplastic automatic machine). Clamping unit *1* is provided with a hydromechanical drive. The molten material is injected into the mould from cylinder *2* under pressure. In the thermoplastic automatic machine,

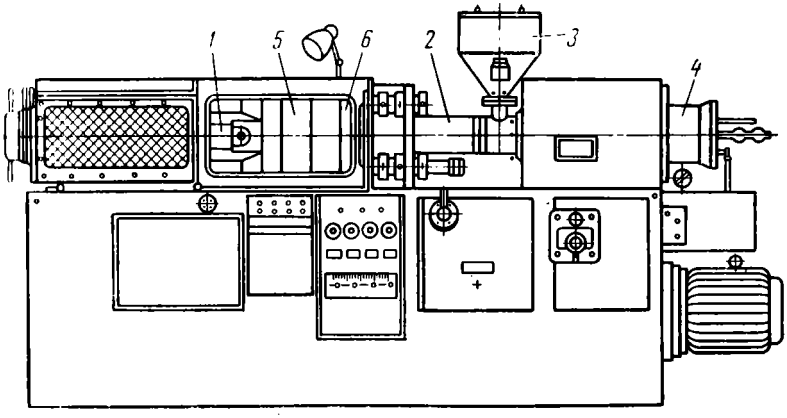


Fig. 136. Thermoplastic automatic machine
1—clamping unit; *2*—heating cylinder; *3*—charge hopper; *4*—hydraulic cylinder; *5*—movable platen; *6*—stationary platen

the injection is performed by a screw conveyer. The design of the injection unit provides for both rotation of the screw conveyer about its axis and its reciprocation along the cylinder axis. When rotating the screw conveyer takes in the next portion of the material delivered from charge hopper *3* and brings it forward, into the cylinder head. To perform the injection, the rotating screw conveyer is stopped and then moved by hydraulic cylinder *4* towards the mould, the screw conveyer acting as a piston.

The thermoplastic automatic machine with a screw conveyer is advantageous as compared to piston machines. The screw conveyer allows only one batch of plastics to be heated in the heating cylinder, the batch being prepared for the next injection. The piston machines are so designed as to simultaneously heat the amount of material exceeding that required for one cycle by several fold. This property of the screw machines is of much importance when processing the thermoplastic materials liable to disintegrate if held for a long time under the temperature required for processing. Another advantage is that the batch of material moved along the axis of the screw conveyer during its rotation is uniformly heated and softened which makes the moulding process easier.

Chapter 16

Moulds for Processing Plastic Materials

16.1. Classification of Moulds

The moulds for making products from plastics come in various designs to suit the manufacture of different articles, the materials they are made from, the production features, etc.

The moulds are classified into compression and transfer ones.

In the *compression mould* (Fig. 137*a*), the loading chamber is a continuation of the cavity shaping the bottom of the article. The part of the mould which accommodates the

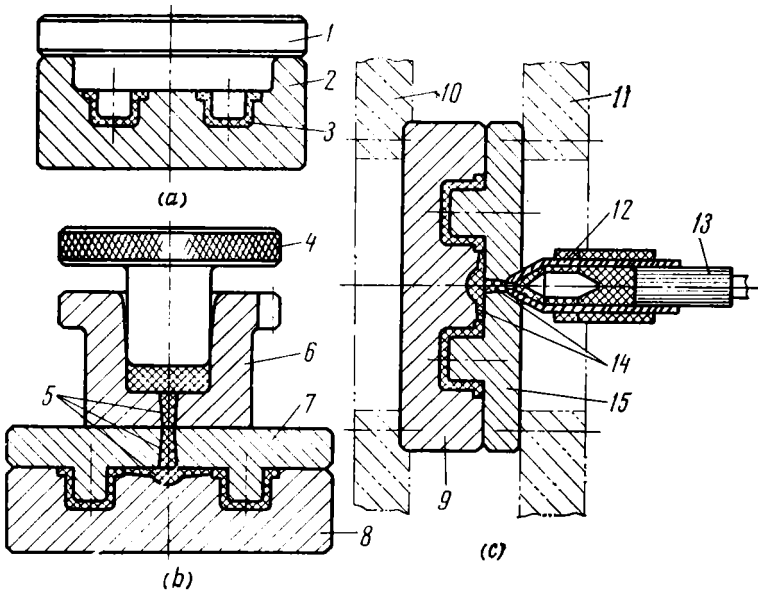


Fig. 137. Diagrams of moulds

(*a*) compression mould; (*b*) transfer mould; (c) injection mould for thermoplastics; *1*, *4*—punches; *2*, *8*, *9*—dies; *3*—article; *5*, *14*—sprue channels; *6*—loading chamber; *7*—upper platen; *10*—rear (movable) platen of injection machine; *11*—front (stationary) platen of injection machine; *12*—heating cylinder of injection machine; *13*—piston of injection machine; *15*—front platen of mould

loading chamber and the bottom shaping cavity is called a *die*. The moulding material is charged into the die where it is heated to become plastic, and rammed by the *punch*. The latter is a part of the mould transmitting the pressure upon the material and shaping the top and internal surfaces of the article. The pressure exerted by the punch upon the material moulds it in the volume of the shaping cavity and imparts it the required shape. The compression mould closes completely when the article is finally shaped.

In the *transfer mould*, the shaping cavity is made separately from the loading chamber and is completely clamped prior to filling it with material. The material comes from

the loading chamber into the moulding cavity through the sprue channels.

There are two basic types of transfer moulds:

(a) with a loading chamber (for use in presses);

(b) without a loading chamber (for use on injection machines).

Figure 137*b* shows a diagram of a transfer mould for use in presses.

The transfer moulds are less efficient than the compression moulds, but they allow more accurate products of intricate shape to be obtained which require no trimming of flash.

The transfer moulds without a loading chamber are used only in the processing of thermoplastic compounds. Such moulds are mounted on injection machines. The material comes into the moulding cavity over the sprue channels from the heating cylinder of the injection machine.

Figure 137*c* shows a diagram of the mould for injection moulding of thermoplastic materials.

As to their maintenance the moulds can be either loose or fixed. The *loose moulds* are to be removed from the press to withdraw the moulded article after each moulding operation. To heat the loose moulds, the presses are equipped with heating platens between which the mould is mounted. The loose moulds are of low efficiency, they are applicable when making small lots of products. The *fixed moulds* are rigidly joined to the platens of the press or injection machine. The ready product is removed from such moulds without removing the mould from the press. The fixed moulds are provided with either a heating or cooling device depending on the type of material to be processed. Besides loose and fixed moulds there are *semi-fixed moulds* wherein only that part which moulds the product is made loose.

From the standpoint of the quantity of products which can be made at a time, or the quantity of moulding cavities, the moulds are classified into *single- and multiple-cavity moulds.* Another distinction between the moulds consists in the number and direction of their parting planes. A *parting plane* of the mould is a term applied to the surface over which the moulding parts open. The opening of the mould is necessary for loading the next portion (weight batch) of

the material to be moulded and for removing the moulded article. The parting (opening) plane can be either vertical or horizontal. To remove the article vertically, the opening is to be made over the horizontal plane. If the removal of the article calls for moving the moulding members apart horizontally, the opening plane is to be vertical. The number of parting planes can be one, two, or three, depending on the shape of the article.

16.2. Moulds for Press Moulding

Let us consider several typical designs of moulds for processing thermosetting materials.

The manufacturers who specialize themselves in making products from the thermosetting materials widely apply compression moulds since they are most efficient. The compression moulding can be used for making articles of different size and shape. However they are not suitable for production of articles with thin metal reinforcements, deep holes of small diameters, or holes perpendicular to the direction of moulding.

Figure 138 shows a *loose one-impression mould with the horizontal parting plane BB for compression moulding* of the transformer housing side. The top mould with punch *5* is closed and locked by guide posts *9* with respect to the bottom. Die *4*, whose top acts as a loading chamber, is of a split design to simplify the manufacturing process. The bottom of the article is moulded by part *3* known as *insert*. Insert *3* is mounted tight in the opening of die *4* and closed by backing plate *1*. In the same way punch *5* is secured in plate *6* (punch holder). Parts *2* and *8* of the mould which shape the holes are called *cores*.

After the moulding operation is over, the mould is removed from the press and placed on a special device to withdraw the moulded article therefrom. The article is removed by stripper *10* whose stems move ejectors *7* through the holes in plate *1*.

Figure 139 shows a *loose one-impression transfer mould with two parting planes AA and BB*. The loading chamber is mounted on top plate *1*. The moulding material fills in the cavity through adapter (sprue bush) *2*. The external outline

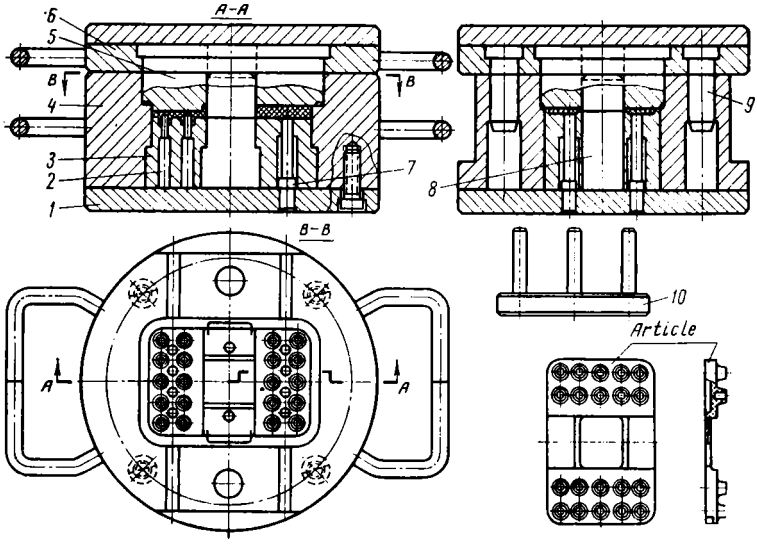


Fig. 138. Loose compression mould
1—backing plate; *2*, *8*—cores; *3*—insert; *4*—die; *5*—punch; *6*—punch holder; *7*—ejector; *9*—guide post; *10*—stripper

of the article is shaped in plates *3* and *4* while the holes are made with the aid of cores *5* and *6*. Central core *7* acts also as a spreader for the plastics flow passing through adapter and directs it towards the face of the article. After the mould is opened over planes *AA* and *BB*, the article remains in plate *4* wherefrom it can be easily ejected by a textolite or aluminium rod.

Figure 140 shows a *fixed compression mould* for making a safety hood from thermosetting material. The mould is of one-impression design with one horizontal parting plane *AA*. The punch which shapes the internal cavity of the article is secured in punch holder *2*. Arranged at the top is plate *1* for heating the punch with four holes receiving the electric heaters. The corners of punch holder *2* are provided with slots (not shown in the figure) for bolts securing the top of the mould to the press platen. The bottom of the mould comprises die *3* mounted on heating plate *6*, support posts

8, clamping plate *12* securing the mould to the press bed, and the mechanism for ejecting the moulded article. The latter comprises ejectors *5* driven by the press lower ram connected to them by means of shank *11*. To preclude misalignment in motion, plates *9* and *10* of the ejection mechanism with ejectors *5* and shank *11* are guided over posts *13*. The separate components of the mould bottom are fastened together by bolts *7*. To reduce the heat loss, the outside of the die is enclosed in asbestos casing *14*.

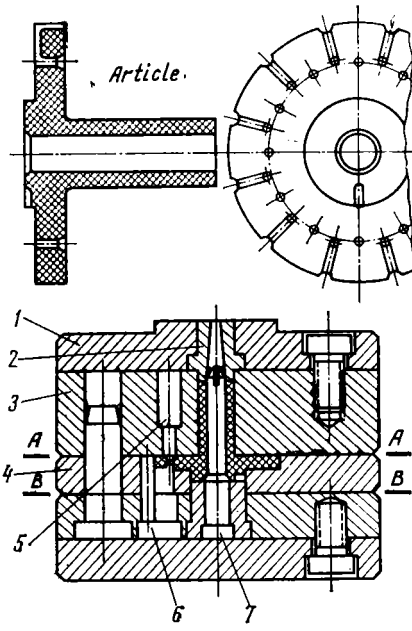


Fig. 139. Loose transfer mould
1—top plate; *2*—adapter (sprue bush); *3*, *4*—working plates; *5*, *6*—cores; *7*—central core

The working principle of the mould is as follows. Prior to moulding, the material is loaded into die *3* of the mould. Then the working ram of the press is engaged and the moulding is performed by descending it. During the operation the punch is kept in correct position with respect to the die by posts *15*. By the end of the stroke of the top ram the mould is completely clamped, and the moulding material fills in the space between the punch and the die and is formed into the article. After the curing necessary for a complete setting up of the article, the top ram of the press is engaged for ascending and the mould is unclamped. Next, to remove the moulded article from the die, the bottom ejection ram is engaged; it actuates upon shank *11* to lift plates *9* and *10*. Ejectors *5* secured in the plates remove the ready article from the die.

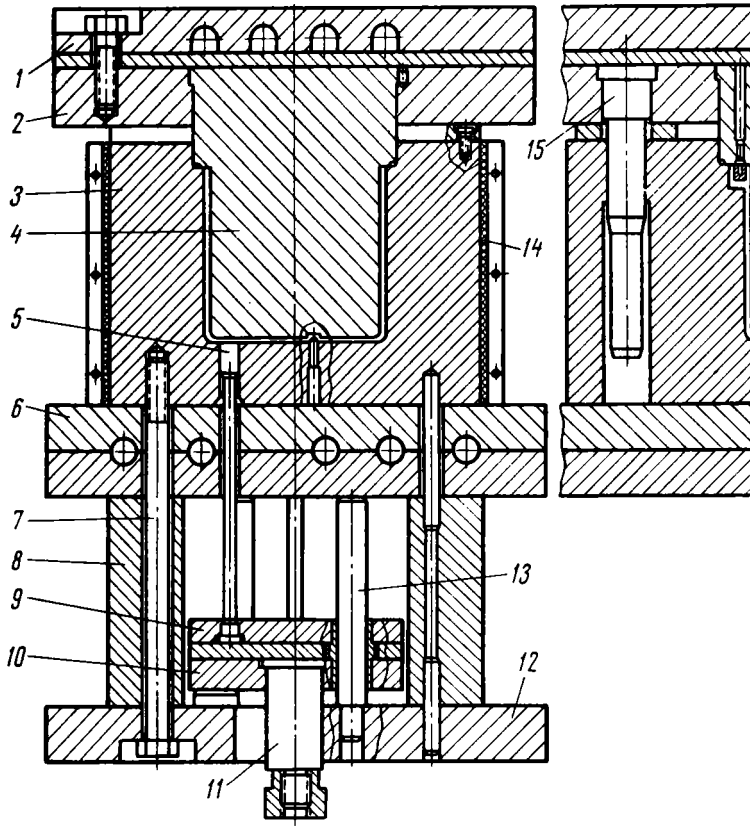


Fig. 140. Fixed compression mould

1—punch heating plate; *2*—punch holder; *3*—die; *4*—punch; *5*—ejector; *6*—die heating plate; *7*—bolt; *8*—support post; *9*, *10*—ejection plates; *11*—shank; *12*—clamping plate; *13*—guide post; *14*—casing; *15*—post

A fixed transfer mould is shown in Fig. 141*a*. Loading chamber *1* made in the form of pipe is arranged in the bottom of the mould. The bottom of the loading chamber accommodates piston *2* which freely passes through adapter *3* in the plates of the ejection mechanism, the piston being joined with the bottom ram of the press. Such moulds can be installed in the ram moulding presses. The top ram is

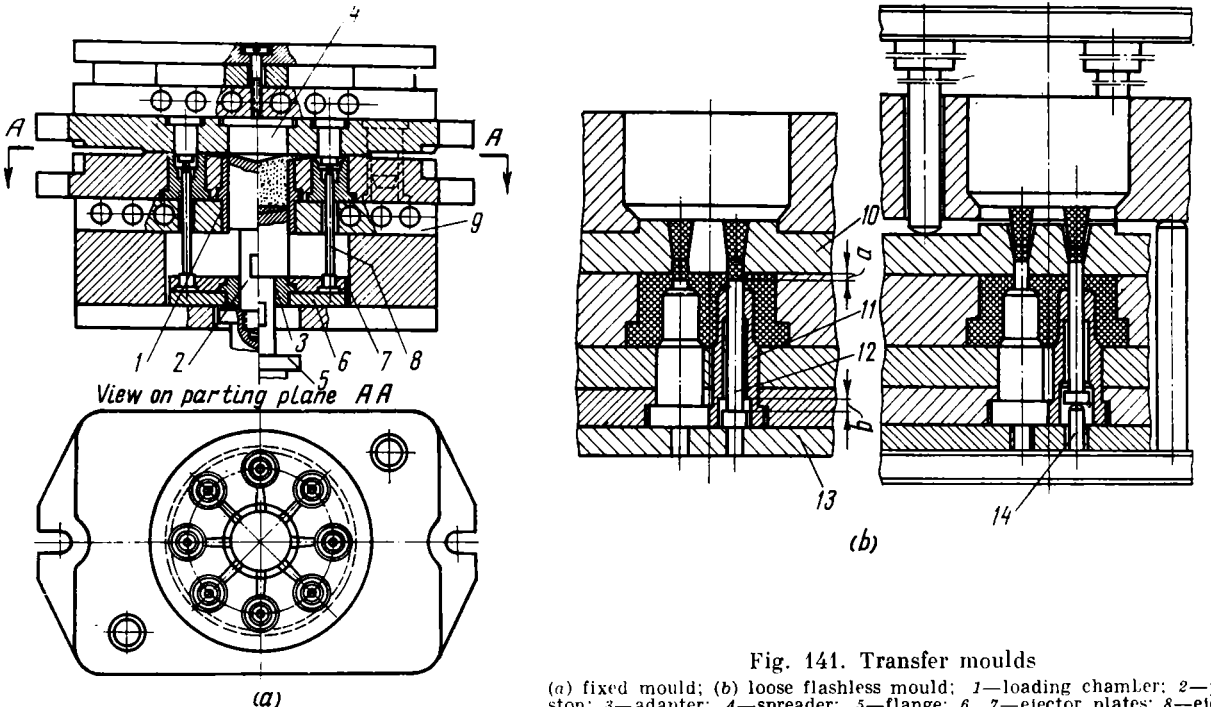


Fig. 141. Transfer moulds

(*a*) fixed mould; (*b*) loose flashless mould; *1*—loading chamber; *2*—piston; *3*—adapter; *4*—spreader; *5*—flange; *6*, *7*—ejector plates; *8*—ejector; *9*—heating plate; *10*, *13*—plates; *11*, *12*—cores; *14*—pin

used for closing and opening the mould over the plane *AA* and the bottom one for delivering the material into the cavity.

The moulding proceeds in the following sequence. When the mould is open, its loading chamber is charged with the material in the form of pellets from the top. Then the mould is closed by engaging the top ram. Thereafter the bottom ram starts operating and lifts piston *2* which delivers viscous-and-fluid material through the sprue channels into the impressions of the mould. Piston *2* goes on rising till its top face reaches spreader *4*. At that moment the bottom ram disengages. With piston *2* in such position, flange *5* of the mould shank, which joins the piston to the rod of the bottom cylinder, is beneath plate *6* of ejectors. After the curing time the mould is opened by engaging the top cylinder of the press. The bottom cylinder is now used to set piston *2* in motion again.

When ascending higher, the piston escapes from chamber *1* ejecting, thus, the remaining material therefrom. At the same time the shank flange raises plates *6* and *7* with ejectors *8* secured in them. The articles which are raised above the parting plane of the mould are manually removed from the ejectors.

Recently a wide application has been gained by flashless moulds for processing thermosetting compounds. The flash or sprues of such moulds are removed either during moulding or when the ready article is being ejected. The application of flashless moulds obviates the need of auxiliary operations of trimming and removing the sprues.

Figure 141*b* shows a diagram of a *loose flashless transfer mould*. Two sprues are brought up to the holes of the article which are made by the use of cores *12*. The cores form the holes not through the entire depth and the moulding material enters the cavity through the clearance *a*. The clearance *b* between the rest shoulder of core *12* and core *11* allows cores *12* to move vertically. When the mould is unclamped, pin *14* of the unclamping device, through the holes in plate *13*, pushes core *12* which rises and cuts away the sprues against plate *10*.

A wide application in the pilot and lot manufacture of plastic products has been gained by *universal units*. A unit is a device mounted in the press and functioning as certain

members in the construction of the fixed moulds. A universal unit is provided with the arrangement for heating the mould, the unclamping unit and the ejection of the moulded article, the fasteners for attaching the unit to the press platens. The components shaping the article (punch, die,

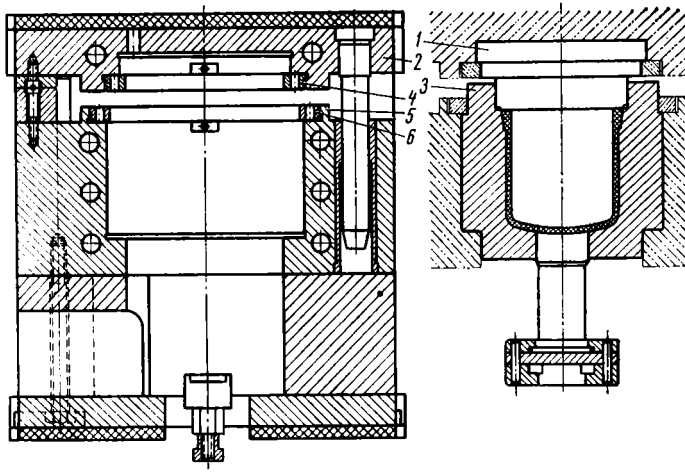


Fig. 142. Universal compression moulding unit
1—punch; *2*—punch holder; *3*—die; *4*, *6*—rings; *5*—case

etc.) are inserted in the universal unit as changeable components. Using the universal units makes it unnecessary to produce a fixed mould for each plastic article. It will be suffice to produce only those components which do the actual work of shaping.

Figure 142 shows the design of a universal unit for changeable moulds, i.e., compression inserts, and a changeable mould for it. Punch *1* of the mould is secured in the round depression of punch holder *2*, die *3* being mounted in the socket of case *5*. The punch and die are secured by threaded rings *4* and *6*.

Modern manufacturers of plastic products employ many different designs of universal units for both compression and transfer moulding.

16.3. Moulds for Reinforced Products

It is a common practice to force metal parts in the plastic material, such parts serving for reinforcement of either the entire article or some of its components. The reinforcement elements can also be used for making strong threaded joints (a bolt or a nut), for fastening the plastic part to the other parts of a structure comprising it. Another purpose of applying reinforcement elements in the plastic article is to secure a terminal or a conductor for convenient wiring of the electrical circuit of an apparatus.

The reinforcement is installed in the mould before moulding. It should be reliably secured in the mould since it receives considerable loads during the moulding process. When making the articles with intricate reinforcement elements, it is usual to use transfer moulds since in such moulds the reinforcement is subjected to weaker pressure exerted by the following plastics.

The size and shape of reinforcement elements, as well as the thickness of plastics round the reinforcement are to be within prescribed values, otherwise rejection may occur. For instance, if the plastics coating round the reinforcement is insufficient, the part will crack. What is worse, this fault may be detected only later on (when the article is in use).

The design of reinforcement has a large bearing upon the labour efficiency in moulding operations and the cost of a mould.

Figure 143*a* shows a four-impression transfer mould for making valve panels. The panel is reinforced by metal terminals and metal flanges. Prior to moulding, the flanges are inserted in the corresponding depressions of die *1* over the mould parting plane. During moulding, the flanges are reliably clamped between the components of mould *1* and *2* so as not to allow the plastics flow to shift them. The terminals are placed in the slots between inserts *3* and *4*. Insert *4* is movable and serves for ejecting the moulded article. The reinforcement elements enter the slots leaving some clearance which can be filled in with plastics during moulding. This calls for periodical cleaning of slots. To facilitate this operation, the reinforcement elements are, as a rule,

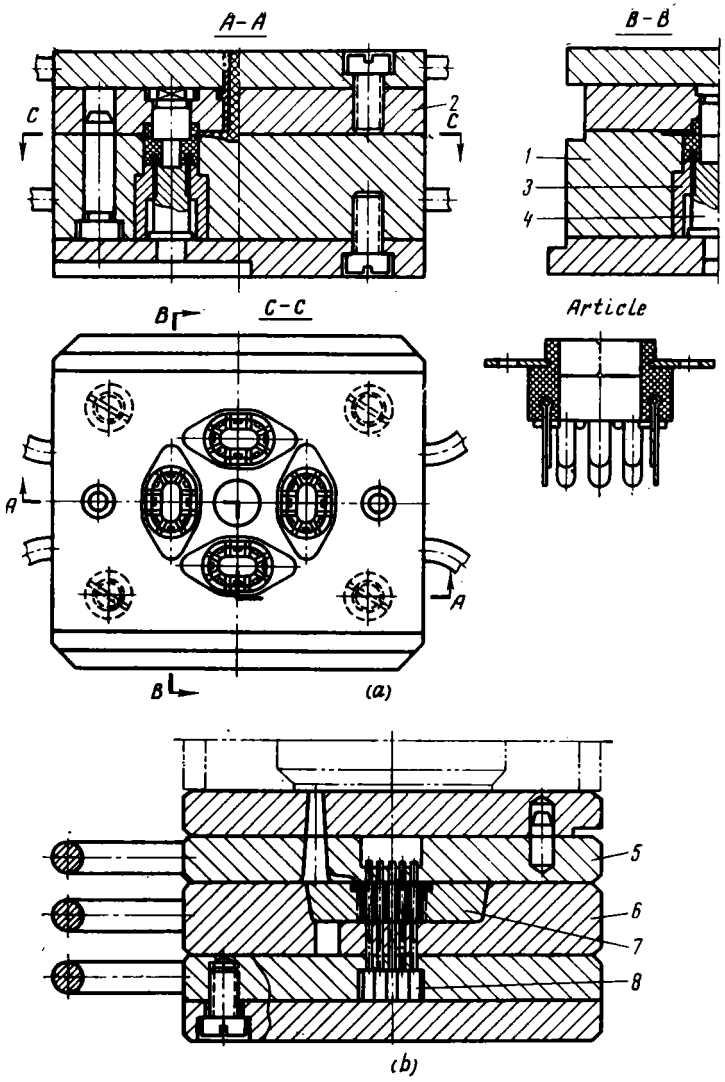


Fig. 143. Moulds for reinforced products

(*a*) four-impression transfer mould for valve panels; (*b*) one-impression transfer mould for products having through cylindrical reinforcement; *1*—die; *2*—punch holder; *3*—insert; *4*—pushing insert; *5*—plate; *6*—case; *7*—die (threaded ring); *8*—core for locking the reinforcement

placed either in the parting plane or in the movable component of the mould. Pushing insert *4* with slots for locking the terminals can be easily cleaned off the plastics got therein when it is in its uppermost position.

An example of reinforcement design is shown in Fig. 143*b*. The article with through contacts is moulded in a one-impression transfer mould. The middle part of the reinforcement (which is in the plastics) is of larger diameter than the protruding ends. This prevents the moulding material from entering the locking holes made in components *5* and *6* of the mould. When the mould is clamped, the middle thicker part of the reinforcement is forced at the faces by plate *5* and case *6* blocking the flow of the plastics into the holes for locking the protruding ends. In this case the design of reinforcement allows a simplified mould to be made without the parting over the reinforcement, which is usually necessary for cleaning the slots.

16.4. Transfer Moulds for Thermoplastics

Figure 144 shows the operating cycle of the transfer mould. The plastic material in the form of hard granules is charged into charge hopper *1*. The amount of granules needed for one injection is automatically batched by the batcher, then piston *2* delivers the granules into delivery chamber *4*. Piston *3* moves to the left and delivers the plastics into heating cylinder *5* heated by electrical heating elements *6* from the outside.

When piston *3* moves to the left, the plastics in the cylinder first moves as a continuous flow and, then, flows around mandrel ("torpedo") *7* and moves in the form of a thin layer through the circular space between the cylinder and the mandrel where it is stirred up well and heated to the moulding temperature.

The moulding cycle begins with the clamping of the mould. The left-hand part of the mould attached to the movable platen of the machine comes up to the right-hand fixed part and, compressing springs *8* set in platen *11*, presses the fixed part against nozzle *10*. After the mould is clamped, piston *3* exerts high pressure to inject the melt into the water-cooled mould.

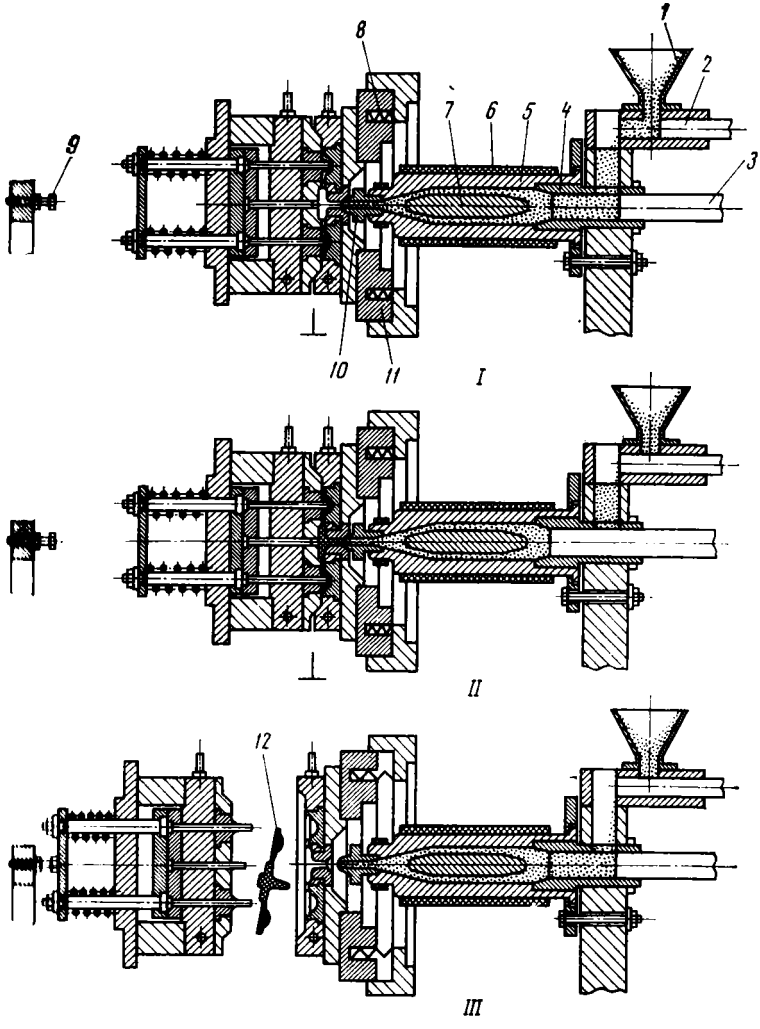


Fig. 144. Operating cycle of transfer mould

I—prior to injection; *II*—injection; *III*—ejection of article; *1*—charge hopper; *2*—batching piston; *3*—loading piston; *4*—delivery chamber; *5*—heating cylinder; *6*—electrical heating elements; *7*—mandrel; *8*—springs; *9*—stop; *10*—nozzle; *11*—platen; *12*—moulded article

To prevent the melt from escaping out of the mould the material must be pressure-cured for some time. Then piston *3* moves to the right and a new batch of the material is delivered from the charge hopper to the delivery chamber. The plastics in the mould goes on cooling off for some time which depends upon the viscosity of the melt and the thickness of the article wall. This period is referred to as *cooling time*. After the cooling time, the movable part of the mould is moved to the left and the mould is opened over the parting plane. At the same time the fixed platen actuated by springs *8* moves to the left from the machine nozzle. With further travel of the movable part, the mould opens completely and moulded article *12* is ejected by the ejection arrangement actuated by stop *9*.

For extrusion of the thermoplastic material continuously the injection machines are used. The main cylinder of such a machine accommodates a rotating screw, hence the name "screw extruders" for such machines, and extrusion for the process. The molten thermoplastic material when escaping out of the heating cylinder passes through the profile hole of the draw plate. The cross section of this hole can be of different shapes. For instance, by the use of a circular draw plate the pipes can be made. On passing through the draw plate the shaped material is to be rapidly fixed to retain the obtained shape for which purpose it is sent to the cooling medium (for instance, water).

16.5. Moulds for Making Rubber Articles

Some rubber articles (absorbers, seals of different types, etc.) can be made by hot moulding. The moulds for such purposes are similar in the design to the moulds for thermosetting materials.

The moulds for processing rubber can be of compression or transfer type, both fixed and loose. Recently the moulders have mastered the manufacture of rubber articles on injection machines for thermoplastics.

In compression moulding of thin-walled rubber parts, such as rings or seals, there is no need in a special loading chamber, which simplifies the design of the mould.

Figure 145*a* shows a *loose compression mould for rubber*

seals. Prior to moulding, uncured rubber is placed, with the punch removed, into the space between ring *2* and die *3*, the space being both a die and a loading chamber at the same time. Then the rubber is covered by punch *1* and set in the hydraulic press which presses against the punch. Under the pressure the rubber gets compressed acquiring the shape of the article which is later removed from the mould following a certain curing time at the prescribed temperature.

The mould (Fig. 145*a*) comprises three components interjoined by taper surfaces which facilitates their disassembly and accurate locking with respect to one another.

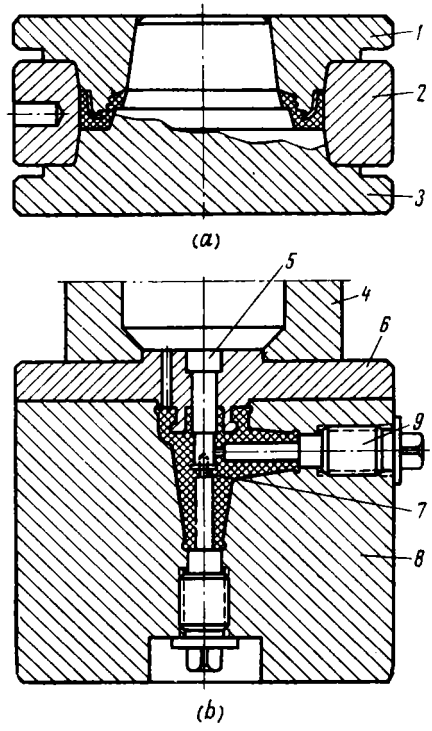


Fig. 145. Moulds for making rubber articles

(*a*) for seals; (*b*) for cap; *1*—punch; *2*—ring; *3*, *8*—dies; *4*—loading chamber; *5*, *7*, *9*—cores; *6*—top platen

Figure 145*b* shows a *loose mould for a safety rubber cap*. This mould is intended for transfer moulding since making a side small-diameter hole by compression moulding involves some risk of breaking the thin-walled shaping core.

Loading chamber *4* is mounted on top platen *6* with core *5*. Before opening die *8*, cores *7* and *9* are screwed out. For simplification, the mould has no additional vertical parting. This makes it more difficult to remove the article. However, the material being elastic, this operation can be performed even for making intricately-shaped articles.

Recently a wide application has been gained by induction heating of the moulds by the current of commercial frequency. Application of induction heating spares power consumption, cuts the heating time, extends the life of electric heaters. The inductors made in the form of copper-wire turns with glass insulation are placed in the slots provided in the heating plate or the mould proper, round the moulding impressions. The inductors are normally lined with liquid glass or high-temperature plastics based on organic silicon.

Figure 146*b* shows a universal unit for transfer moulding of thermosetting materials.

The loose moulds are mounted on platen *6*. In the process of mounting the mould is set on the protruding part of loading chamber *8* made in the form of a tube. The loose moulds are heated by an induction method with induction elements *7* arranged in the slots of platens *5* and *6*.

The interaction of the unit components is similar to that in the fixed mould described in Fig. 141*a*.

16.7. Mould Components

The mould components are classified into two main groups:

(a) the manufacturing components, i.e., those coming into the immediate contact with plastics and, thus, imparting the article the required shape. These are a die, a punch, bushings, cores.

(b) the structural components which do not participate in moulding but ensure the operation of the first-group components. These are guide posts, support plates, pushers, handles, etc.

Dies and cases. The die is the basic component of the mould doing the work of moulding the outside of the article. The shape, dimensions, and design of the die are governed by the design of the article to be moulded. In compression dies, the bottom of the die moulds the article and is, thus, the die cavity proper whereas the top is intended for receiving the material and is, thus, the loading chamber.

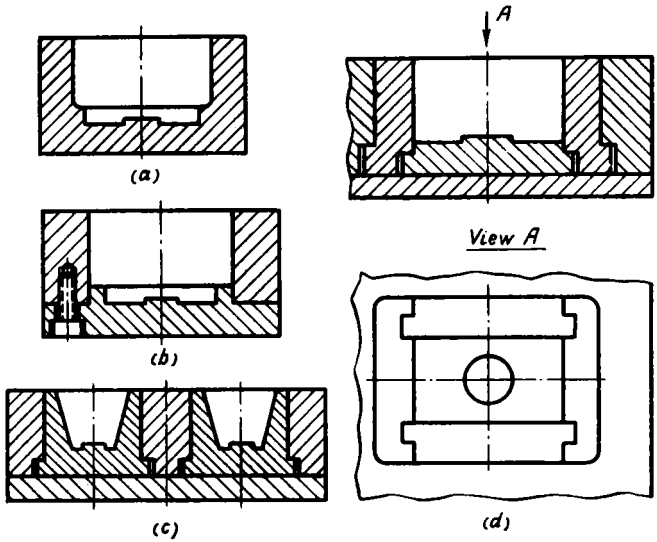


Fig. 147. Design of dies
(*a*) one-piece die; (*b*), (*c*), (*d*) split dies

It is not always easy to make *one-piece dies* (Fig. 147*a*), and, therefore, *split dies* are often more reasonable (Fig. 147*b*); the joining of the die proper to the loading chamber should be done so as to prevent any material from getting into the clearance between them in the process of moulding. When the material gets into the clearances under high pressure it gradually loosens the joint and the mould gets out of order.

In multi-impression moulds use is made of *insert cylindrical dies* press-fitted in a case (Fig. 147*c*). A case is a part designed for holding together the moulding components which form a sectional structure. The cases are most often used for joining the components of the sectional moulding impressions, also known as cavities.

Though the case comprises and helds together a great variety of components, it is of a rather simple design. The cases are usually round or rectangular. The case does not take part in moulding but it does receive severe loads dur-

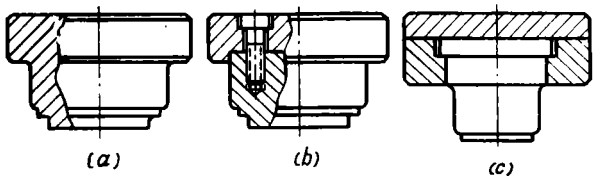


Fig. 148. Design of punches
(*a*) one-piece punch; (*b*), (*c*) split punches

ing the moulding operation and is, therefore, one of the critical components.

For moulding large-size articles (even of a simple shape) the dies are made split and comprise several components of a simple shape (Fig. 147*d*).

Punches. A punch is the basic component of the mould, which moulds the top part and the internal surface of the article. The punch of a compression mould imparts the pressure of the press to the material. Small moulds employ *one-piece punches* (Fig. 148*a*) but this leads to unsparing use of tool steel. This is why *split punches* (Fig. 148*b* and *c*) are preferable.

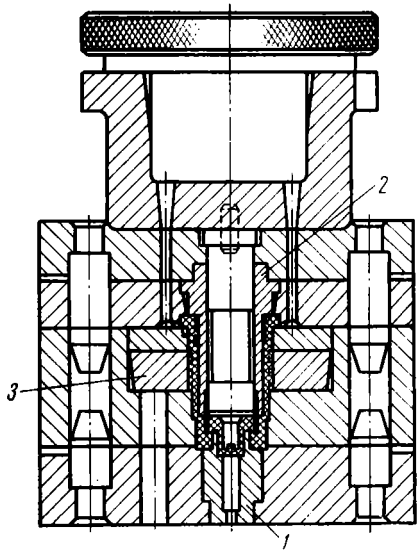


Fig. 149. Transfer mould
1—bushing; *2*—core follower; *3*—ring follower

Bushings. When moulding intricately-shaped articles, the punch and die may take a complex shape which involves difficulties for machining. Application of bushings facilitates making and repairing punches and dies of intricate shape. Bushings *1* (Fig. 149) are those components which are mounted in the punch or die to mould depressions or holes of

different shape in the articles. The bushings are mounted either fixed or so as to remove them after each moulding.

Ring followers and core followers. The plastic articles are threaded with the aid of core followers or ring followers. The internal threads are moulded by core follower *2*. Core followers are placed in the mould prior to moulding, they are removed together with the articles and removed from the threaded holes by special extractors. The external threads are moulded by ring follower *3*. As a rule the ring is screwed off the moulded article after it is removed from the mould.

16.8. Accuracy and Surface Finish of Moulds

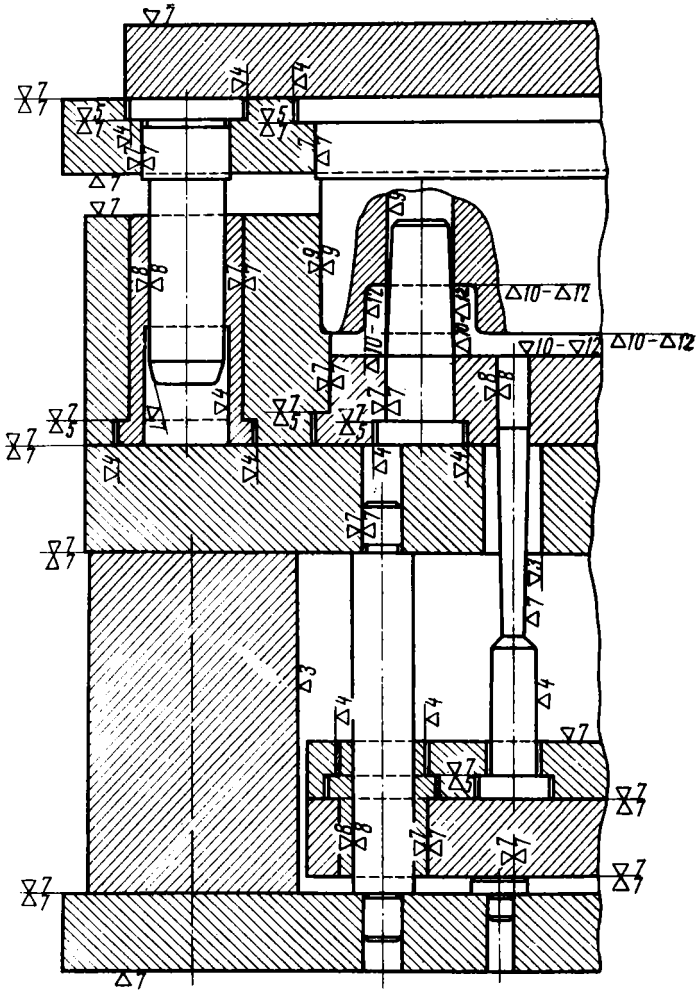
The surface finish and the nature of joints of mould components are of great importance for their proper maintenance. Special attention should be paid to the surface roughness of the moulding components since this influences the quality of articles. The surface finish of the moulding components should comply with Class 10-12. The moulding surfaces are chrome-plated to reduce their wear and to remove easily ready articles.

The surfaces which contact the plastics but take no part in the moulding (such as the sides of punches, the surfaces of loading chambers, sprue channels) should be finished to Class 9, the mating surfaces of movable guide components (such as posts and bushings) should be not worse than Class 8. The surfaces of plates should be at least of Class 7 but this does not mean that they need such high finish but is dictated by their obligatory mutual parallelism which is a usual result of machining on grinding machine tools.

Figure 150*a* describes surface finish classes for each particular component of a mould.

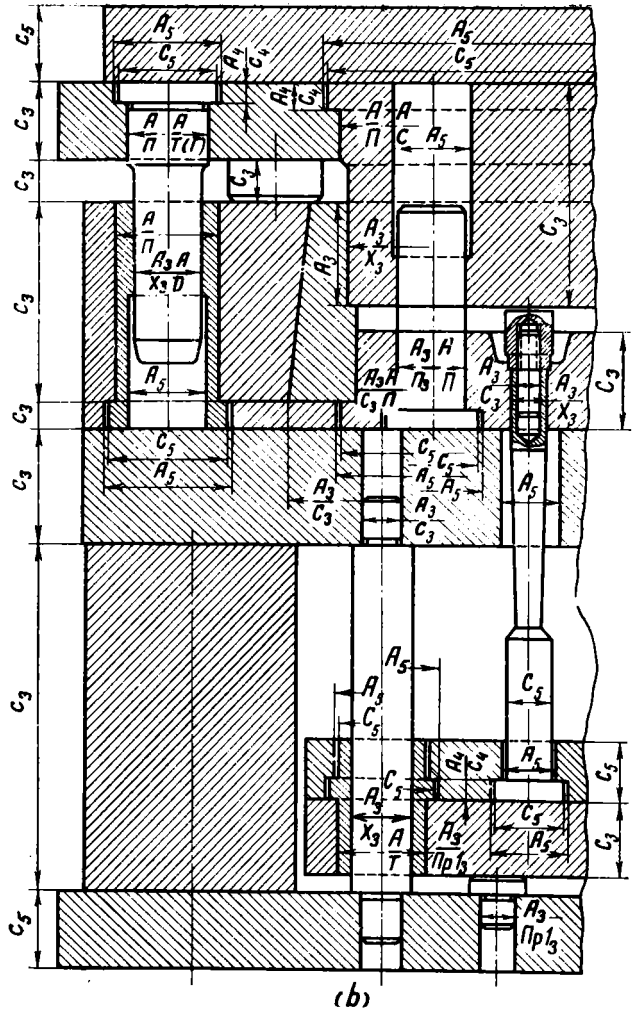
When choosing the type of fit governing the nature of joint of the mating components, one should proceed from the purpose of the joint and its working conditions. The members of the moulding components doing the actual work of moulding are made to Class 3 accuracy.

The movable members of the dies and ejectors whose surfaces are subject to friction are made to Class 2 or 3 accuracy providing the running fit. The maximum clearance



(*a*)

Fig. 150. Surface finish classes (*a*) and



fits of mating components in mould (*b*)

in the movable joint which may admit the flow of plastics should not exceed 0.05 millimetre. The fixed members of the moulding components are assembled to slide or push fits with Class 2 accuracy. The member of a fixed mould shown in Fig. 150*b* and the suggested fits give an idea of the nature of mating between different components of the mould.

Chapter 17

Manufacture and Repair of Moulds for Making Plastic Articles

17.1. Selection of Materials for Manufacture of Mould Components

The critical components serving the manufacturing purposes are mainly made from alloy tool steels. The components of the structural nature are made from structural steels (Table 11). The steels used for the manufacturing (moulding) components are expected to possess high mechanical properties, good abrasion resistance, and to resist well to the deformation while heat-treated, which is especially important when the moulding cavity is of a complex design.

When making single pieces under pilot production it is reasonable to use temporary moulds made from unhardened steel, the thermosetting materials in such cases are moulded in moulds made from non-ferrous alloys or even from plastics.

17.2. Methods for Machining of Mould Components

Since the moulds come in a great variety of designs it is rather difficult to prescribe accurately the manufacturing methods for either a mould as a whole or its components. Nevertheless most of components can be made according to one of the following two methods:

(1) All the components, having the shape of body of revolution, being flat (without projections or depressions),

Table 11

Grades of Steel Used for Manufacture of Mould Components

Mould components	Steel grades	Type of heat treatment	Hardness R_C
Moulding components of complex shape	12XH2A; 12X2H4A; 12XH3A; ХГ; ХВГ	Carburizing and hardening	50-55
	5XB2C; X12	Hardening	50-55
	X12M	Same	50-55
Moulding components of simple shape	У8А; У10А	Hardening	55-58 50-55
Punch holders and support plates	Steel 3, 15. 20, 30, 45	Hardening	40-45
Ejectors, rods, long pins	У7А; У8А; 40X	Hardening	42-47
Posts and guide bushings	У8А	Hardening	45-50
Limits and stops	Steel 15, 20	Carburizing and hardening	45-50
Plates, rests, support plates	Steel 3, 15, 20	—	—
Cases for split punches and dies	Steel 35, 45	—	—
Inclined dowels	X12, X12M, 7X3	Hardening	38-43
Dowels for pressing-out devices	Steel 5, 30	—	—
Springs	Steel 70	Tempering	—

or of any other shape which allows their machining after heat treatment by grinding on machine tools, are rough machined and bench fitted. The heat-treated and ground components, depending on their purpose, are finished and polished.

(2) The intricately-shaped components whose grinding is impossible are finish-machined prior to heat treatment and then finished and polished. If some members of such components are liable to deformation in heat treatment, an allowance should be left which is later removed mechanically or manually.

The machining of mould components calls for employment of various machine tools: screw-cutting lathes, milling, shaping, drilling, jig-boring, grinding, profile grinding, jig-grinding, electrospark, ultrasonic, engraving, filing, form-shaping machines.

Application of machine tools considerably cuts consumption of labour spent on bench jobs needed to make the components and prepare them for assembly.

Figure 151 presents several possible versions of the manufacturing process involved in making the same part, for instance, the die of the mould for plastic handle for

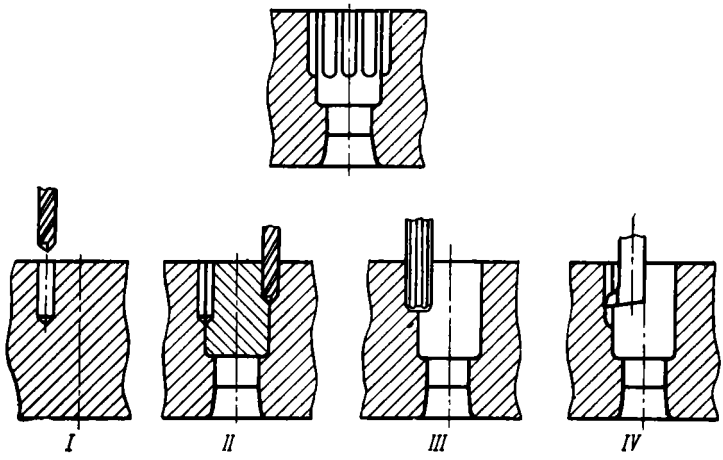


Fig. 151. Methods of making moulding cavities of die

an instrument. Such a die can be made by one of the following methods:

(1) *on a drilling machine* (diagram *I*): the blank is marked, the holes which form the corrugation outline are drilled and, then, trimmed with a specially-ground reamer; the centre hole of the die is drilled and bored on a lathe; thereafter the die is heat-treated and ground;

(2) *on a jig-boring machine*: the corrugation holes are drilled in the die blank to the prescribed depth as in diagram *I*, the centre hole is drilled and bored, the die is ground by hand and, finally, handed over for heat treatment and polishing;

(3) *on a lathe and a drilling machine* (diagram *II*): first the moulding cavity (centre hole) is bored, then a plug of similar metal for this cavity is lathe-turned and press-fitted therein, then the plug is forced out, the moulding cavity is ground, heat-treated and polished;

(4) *on a vertical milling machine* (diagram *III*): the die blank is mounted on a lathe and the centre hole is drilled, the corrugation is made on a vertical milling machine using the end mill and mounting the blank in the vertically arranged dividing head;

(5) *on a form-slotting machine* (diagram *IV*): similar to the previous case, first the centre hole is bored and the corrugation outlines are shaped on a slotting machine by a slotting tool dressed according to the corrugation outline.

Each particular method for making a die is decided upon proceeding from the working conditions and the available equipment.

Let us consider one of the versions of the manufacturing consequence of machining another component of the mould. Taken as an example is the punch of a loose compression mould shown in Fig. 152.

Operation 1. Milling. A steel blank made in the form of a forging with the size of $37 \times 57 \times 62$ millimetres is delivered to the mechanical division of the tool shop where the following operations are performed. The forging is milled observing the dimensions of $31.4_{-0.1} \times 52_{-0.1} \times 57.2_{-0.1}$ millimetres and the corner of 90° between the edges, the hole of 12-millimetre diameter is drilled in the centre for

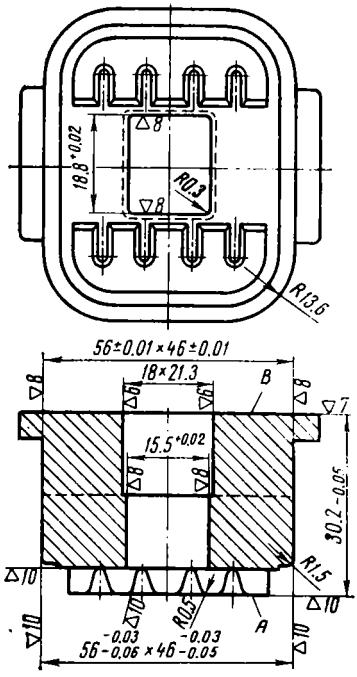


Fig. 152. Punch of loose mould

the tool to be introduced when performing the slotting operation.

Operation 2. Toughening. In this particular case the operation is performed to relieve the stresses due to forging and rough milling, which cause the warps on the component during hardening.

Operation 3. Grinding. The operation provides datum surfaces for further machining and preparing the surface for marking the moulding outline. The blank is ground on six sides observing the corner of 90° and the dimensions of $30.8^{\pm 0.01} \times 52^{\pm 0.01} \times 56^{\pm 0.01}$ millimetres.

Operation 4. Boring. The working outline is marked on the plane *A* at the side of the moulding face of the future punch, this being done on a jig-boring machine. Marking is done very accurately to the drawing dimensions by a sharp centre held in the boring machine spindle. In the corners of rectangular port the boring operator drills four holes of 0.6-millimetre diameter (spaced at least 0.03 millimetre from the marked off outline). These accurately spaced holes will later serve for correct positioning of the workpiece when filing the port, leaving the allowance of 0.03 millimetre for finishing. At the side of the face *B* two processing holes are bored for the workpiece to be locked on them when milling (breaking-in) the radii $R = 13.6$ millimetres on the adapter processing plank.

Operation 5. Milling. The working outline is milled to the marking with a dimensional allowance of 0.05 millimetre for bench trimming and finishing. The punch surfa-

ces where grinding is possible after heat treatment are milled with a grinding allowance of 0.3 millimetre per side. In this case the locating size of the punch of 56 × 46 millimetres and radii $R = 13.6$ millimetres are milled with a grinding allowance.

The radii are broken-in placing the punch on the adapter processing plank and on two processing holes made by boring to the face *B*. The milling depth of the moulding face is prescribed with an allowance of 0.3 millimetre on the plane *A*. At the side of the face *B* the centre port is widened by milling up to the size of 21.3 × 18 millimetres. This facilitates the bench filing of the port since the filing surface becomes smaller. The centre port is deepened by milling by 4-5 millimetres (the distance to the marked off contour is 0.15 millimetre from each side). This facilitates the next operation of slotting.

Operation 6. Slotting. The milled rectangular port is slotted with an allowance for bench filing of 0.15 millimetre per side.

Operation 7. Bench fitting. The benchman files the port observing the dimensions over the edges of holes made in the corners and leaving an allowance of 0.02 millimetre per side for finishing after heat treatment. Thereafter the benchman trims the working outline and the surfaces which will need no grinding. Since high surface finish is difficult to obtain on the non-hardened work, the final trimming and finishing are performed after heat treatment. The allowance for this is two or three hundredths of a millimetre.

Operation 8. Hardening. The workpieces to be hardened are heated with no admission of oxygen in a salt bath or in a case with coal, which protects the surface against scaling and saves time in further bench trimming.

Operation 9. Bench fitting. The benchman is responsible for the finishing of the punch working outline to the degree specified in the drawing (except for the places to be ground).

Operation 10. Grinding. Both faces of the workpieces are ground observing the sizes specified in the drawing. The locating size of the punch 56 × 46 millimetres is also ground, as well as the radii $R = 13.6$ millimetres and $R = 1.5$ millimetres. The radii are machined on the surface-grinding machine using a profile grinding wheel.

Operation 11. Bench fitting. The benchman imparts the ground surface the required finish (in this case ▽ 10) and dresses the radii $R = 0.5$ millimetre on the face A.

Operation 12. Chrome-plating.

Operation 13. Bench fitting. The benchman polishes the chrome-plated moulding surfaces imparting them mirror-like glance.

The above example of planning the manufacturing process for making punches is one of the possible versions. This process can be varied to suit particular working conditions.

The above-described process is based on the maximum employment of machine tools, leaving small allowances for the benchman to file the locating places, to trim, to lap, and polish the working outline.

Let us consider the manufacturing process of making a die for a transfer mould (Fig. 153), which also conveys an idea of some features involved in the making of moulds.

The operational sequence of making a die is as follows:

Operation 1. Planing. The blank is planed observing the size of 110.6 × 180.6 × 19 millimetres. During the same operation four recesses C are made.

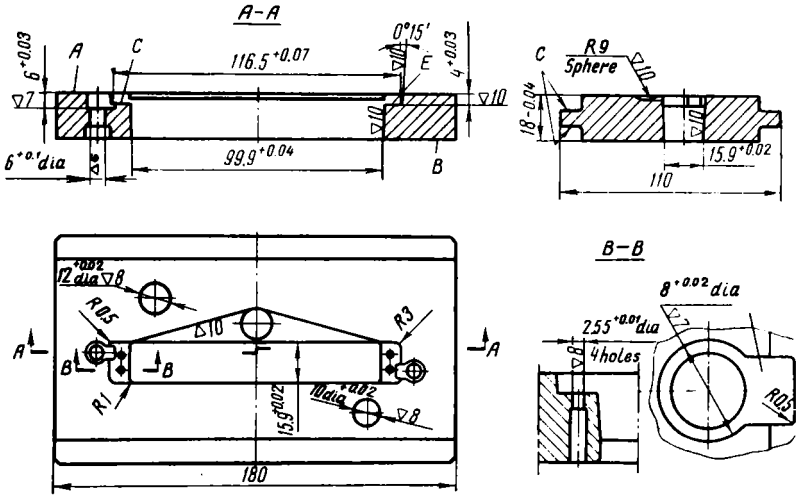


Fig. 153. Die for transfer mould

Operation 2. Toughening.

Operation 3. Grinding. The blank is ground on all sides observing mutual perpendicularity and the size of $18.4^{+0.01} \times$ $\times$ 110 $\times$ 180 millimetres. In this case the sides of the die are not either moulding or locating members, they are finished to the drawing.

Operation 4. Boring. This operation underlies the accuracy of the basic sizes of the future component. All the holes are bored whose mutual spacing and position with respect to the datum surface must be accurate. In this case these are two holes for guide posts $10^{+0.02}$ and $12^{+0.02}$ millimetres in diameter, four holes $2.55^{+0.01}$ millimetres in diameter, two holes of $6^{+0.1}$-millimetre diameter, and two holes with a diameter of $8^{+0.02}$ millimetres. The surface with roughness ∇ 7 and over are bored leaving an allowance of 0.02-0.03 millimetre for further finishing.

Besides providing accurately coordinated holes the boring operator also marks the contour facilitating further operations. In this case the port of 15.9 $\times$ 99.9 millimetres with depressions 116.5 millimetres is marked, as well as two flats D, a sprue, and the centre of a sprue sphere $R = 9$ millimetres. The holes 6.2 and 1 millimetres in diameter are bored or drilled in the corners of the port and flats D, leaving the space of 0.03 millimetre from the marked off contour.

During the boring operation besides the working contour the component members requiring no high manufacturing accuracy, i.e., the sprue and the sphere $R = 9$ millimetres are marked as well. This marking facilitates the job of the miller or the lathe operator, serving as a reference for verifying their work to the marking, but does not make the boring operation more complicated at all.

Operation 5. Lathe machining. The lathe operator bores the sphere $R = 9$ millimetres with surface finish of ∇ 9. No allowance for the specified surface finishing of the hardened and chrome-plated sprue hole is prescribed since the dimensional accuracy is of minor importance in this particular case.

Operation 6. Milling. In the place of the port of 15.9 $\times$ 99.9 millimetres two holes 12 millimetres in diameter are drilled for the slotting tool to be introduced at the next operation.

Operation 7. Slotting. A port is slotted to the marking keeping 1.5 millimetres from the contour and leaving a web of 8-millimetre width in the middle. This web will save the component from warping when it is hardened.

Operation 8. Milling. The port and the rest of depressions are milled to the marking. An allowance of at least 0.05-0.08 millimetre is left in the port for bench trimming and finishing, the allowance in the other depressions and the sprue being 0.02-0.03 millimetre. This can be explained by the fact that hardening distorts the port contour heavier than other places, the correction of the port calling, thus, for larger allowance. The depression of 15.9 × 116.5 millimetres is milled while making an angle of 0°15′ over the entire contour. This can be achieved by the use of a special mill ground to the required angle.

Operation 9. Bench fitting. The benchman trims the milled surfaces.

Operation 10. Hardening.

Operation 11. Cutting off. The processing web in the middle of the port is cut off on the tool-grinding machine using a vulcanite wheel.

Operation 12. Bench fitting. The benchman trims the hardened horizontal sections E, which is necessary for accurate sizing in further grinding of die surfaces.

Operation 13. Lathe machining. The lathe operator polishes the sphere $R = 9$ millimetres prior to chrome-plating and laps the precision holes with higher surface finish removing the allowance left after boring. This job can also be done by the benchman but it is usually assigned to the lathe operator because lapping may often call for making special laps whose sizes cannot be predetermined.

Operation 14. Grinding. The die surfaces are ground to size $18_{-0.04}$ millimetres, observing the sizes $4^{+0.03}$ and $6^{+0.03}$ millimetres.

Operation 15. Bench fitting. The benchman finally trims and finishes the moulding surfaces observing the drawing dimensions. The parting plane is lapped on the surface plate to the surface finish ∇ 9.

Operation 16. Chrome-plating.

Operation 17. Lathe machining. The chrome-plated sphere R = 9 millimetres is polished on the lathe.

Operation 18. Bench fitting. The benchman polishes the moulding surfaces.

The above example illustrates that making even a rather simple component involves many operations, including seven types of machine-tool operations. The mould manufacturers face a task of correct employment of the available equipment to reduce inefficient manual work and to make, at the same time, a component which complies with the drawing specifications.

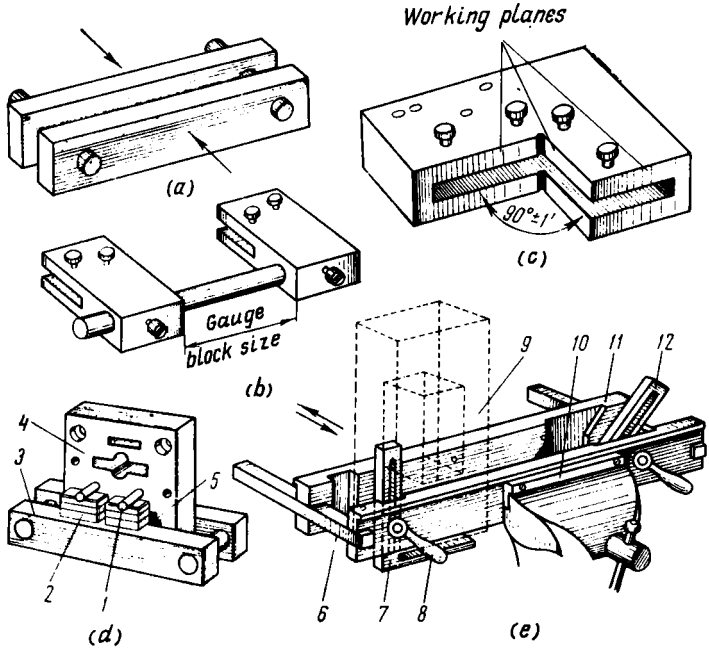
17.3. Bench Fitting of Mould Components

Filing accounts for much part of bench fitting when making moulds. It has some special features. These involve the following: the sequence of filing the component sides, application of correct methods for obtaining the plane and profile surface, and efficient methods for obtaining symmetrical profile elements.

The sequence of filing the sides influences the quality of the ready article. First the side with the largest surface should be filed so as to provide a reliable datum surface for further operations. Next the side which is parallel to it should be filed. Thereafter the narrow side of the largest size should be dealt with (the other datum surface). Using the first and third sides of the component as datum surface allows correct filing of the rest of the sides irrespective of the sequence chosen for their filing. The benchman should only concern himself with keeping the sides perpendicular and parallel with respect to datum surfaces.

To properly file the flat surfaces usually is difficult not only for the beginner. Therefore it is good if filing is done with the aid of filing jigs. These are made in the form of frames made from hardened steel (Fig. 154*a*, *b*, *c*).

The component is set inside the jig so as to overhang its planes only by the amount of the filing allowance. Then the jig and the component are fastened in the vice and the component is filed till the file touches upon both hardened surfaces of the jig. Figure 154*d* shows an example of filing the outline to the jig. The jig is mounted by the use of processing or working holes of the die or its datum surfaces parallel to the tracing plane of the jig. Inserted in the da-



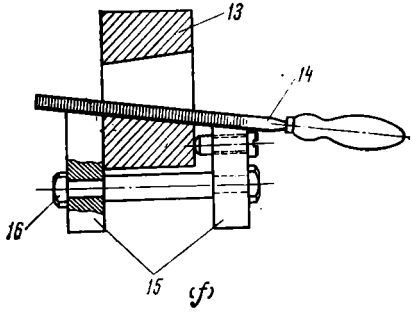


Fig. 154. Bench filing jigs

(*a*) plane filing jig; (*b*) slot filing jig; (*c*) right-angle filing jig; (*d*) mounting the die to jig; (*e*) filing jig with square to mount the workpiece; (*f*) filing of through inclined port in die; *1*—shaft; *2*—gauge block; *3*—jig; *4*—die; *5*—port; *6*—guide plate; *7*—square; *8*—handle; *9*—workpiece; *10*—jaw; *11*—parallel plate; *12*—mounting plate; *13*—case; *14*—file; *15*—parallel blocks; *16*—guide pins

tum holes are shafts *1*. Then die *4* is set on gauge block *2* and secured in the vice together with jig *3*. After the blocks and shafts are removed, the lower surface of port *5* is filed till the file touches upon the hardened surface of the jig.

Use is also made of the jigs provided with additional devices allowing the benchman to correctly and easily mount the workpiece. Figure 154*e* shows a jig consisting of two parallel plates *11* secured in special jaws *10* of the bench vice, two guide plates *6*, mounting square *7*, and mounting plate *12*. The square and plate *12* are secured in the required position by handles *8*. Workpiece *9* is mounted to square *7* or plate *12*, which ensures its stable position in spite of frequent resettings. Square *7* also serves for an accurate swivel of the work through an angle of 90° when dealing with mutually perpendicular areas of the shape. Guides *6* ensure dead-parallel travel of plates *11*, which keeps the work in the required position when it is re-clamped.

The plates and the square are made from carbon tool steel and heat-treated to hardness of R_C 60-64, then their surfaces are ground, and the slots for travel of the guides and the square are lapped.

Obtaining profile surfaces is one of the most difficult bench jobs, but it can be facilitated by the use of master forms. On the other hand, filing with master forms proves reasonable mainly in lot production since making a master form, which must be a replica of the part shape, is labour-consuming and expensive job. A shaped part can be filed to a jig too but this method is less accurate.

When making mould components of shaped profile the filing can be done element by element. In such case the benchman will use master forms only for filing some of the elements. Making such forms involves no special difficulty. Filing by the use of master forms applied only to some of the elements calls for greater skill than filing to one common form or to the marking.

Filing the internal outlines of the mould cases and dies is a most labour-consuming job which can be considerably facilitated by applying filing machines.

When filing the through tapers of the ports which are rather frequent in the mould cases, it is good to use pa-

rallel blocks (a jig) with a bevel on the working surface made beforehand. This device can be seen in Fig. 154*f*.

Case *13* is forced between blocks *15* which pilot file *14* during operation. The blocks are made from tool steel and hardened. Guide pins *16* are made to Class 1 accuracy and finished. These pins are set in blocks *15* to slide fit, which provides for their strict parallel travel with respect to each other. For the fastening of the mounted case applying the gauge blocks from the port holes or from another datum surface the blocks are screwed to each other by screws (not shown in the figure). This allows the device to be removed from the vice when necessary without distorting the correct position of the mounted component with respect to the upper surface of the blocks. Using such a device the benchman will never mar the surface being filed even when the file happens to slant. The master forms used for element-by-element filing of the shaped ports in the mould components not only provide for correct filing of a certain area of the outline but also protect the surfaces which are not supposed to be touched upon by the tool.

For instance, in the central port of insert *2* (Fig. 155*a*) there are some straight sections adjacent to radii $R = 2$ millimetres.

Filing them, prior to hardening, in the parallel blocks (in a jig) the benchman can incidentally touch upon the radial surface with a file and mar it. To avoid this, it is advisable to make master form plate *1* and mount it in the vice together with insert *2* locking it in two holes $6^{+0.01}$ millimetres in diameter. Hardened plate *1* will guard against damaging the radial surface ($R = 2$ millimetres), its plane *A* serving as a master form for filing the straight sections adjacent to the radii. For greater convenience two plates *1* can be positioned on both sides of the port of insert *2*. This will allow even a beginner to accurately file the ports of very intricate shape.

Since plate *1* was used for filing prior to hardening, it was made to the size allowing for finishing the insert port after heat treatment.

Another example of filing operation requiring a hardened block to protect radial surfaces when filing the planes is shown in Fig. 155*b*.

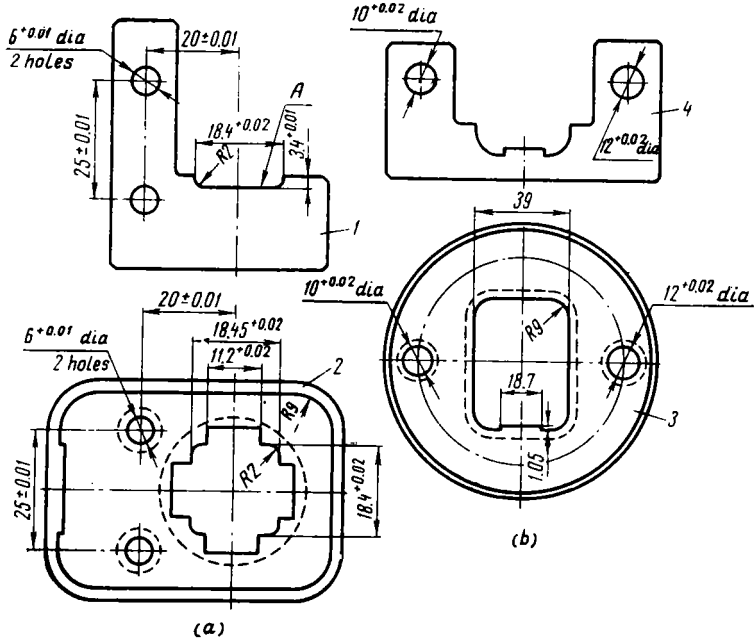


Fig. 155. Master forms for filing shaped surfaces of ports
1, 4—master form plates; *2*—mould insert; *3*—case

In doing so it is difficult to file the straight sections of the port in case *3*, which are between the projections 18.7 millimetres and radii $R = 9$ millimetres of the port. To facilitate this operation, it is good to use a hardened master form plate *4* placing it in front on the port to be filed locking it by means of two holes for posts ($10^{+0.02}$ and $12^{+0.02}$ millimetres in diameter).

The above-described master form plates can be made with a high degree of accuracy, since their shape allows the working surface to be ground on the machines after hardening.

The locking holes are made on the jig-boring or jig-grinding machines.

Making different auxiliaries does not involve much dif-

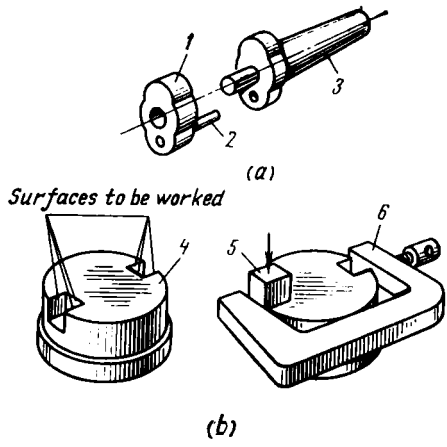


Fig. 156. Application of master form for filing shaped surfaces of core (*a*) and caulking to shape closed slot (*b*)

1—master form; *2*—pin; *3*—core; *4*—part (insert); *5*—caulking chisel; *6*—screw clamp

ficulty but their application makes bench filing an easier matter and improves the quality of moulds.

To file the external outline, a frequent use is made of such master forms as shown in Fig. 156*a*. This master form *1* is good to deal with the shaped surface of core *3* when making a batch of articles of similar design. Such cores are usually made to mould the holes in the article. Design of core *3* allows the master form to be mounted on the central rod locking it against unnecessary turning by pin *2* entering the processing hole on the core.

The master form and the machined core assembled are held together by a screw clamp. Filing is done in the vice guiding the file over the surface of the hardened master form. Using the master form considerably facilitates the bench fitting and ensures identical sizes in the whole batch of the cores filed.

When bench fitting the different depressions in the moulding components, which cannot be filed, caulking chisels (Fig. 156*b*) can be resorted to.

Caulking chisel *5* is made of tool steel hardened to the maximum degree of hardness. The caulking chisel of a shape answering for that of the future article is attached to part *4* by screw clamp *6*. From time to time the caulking chisel is taken off the part to remove chips. The operation is done in a single pass.

The most labour-consuming job of bench fitting is to deal with rectangular or shaped ports of small sizes in the moulds. It is a good practice to handle them with bench broaches. Broaching is performed on a hand press using a jig for the correct guiding of the broach and protecting it against damage (see Chapter 9). Broaching takes several passes. The size of each subsequent broach exceeds the previous one by 0.1-0.15 millimetre. The intricately-shaped holes are first broached element by element and then sized finally by the broach made to the full profile of the hole.

17.4. Checking Up the Profile of Mould Working Surfaces

The working profile of the moulding components ranks often among the profiles which cannot be checked up by all-purpose measuring tools. A standard practice is to make a set of flat templets which are then applied to certain areas of the moulding component to see how tight they are against the surface by means of a feeler gauge or observing the clearance.

Flat templets can be used for both checking up a ready component and testing it while it is being made. The auxiliary templets are used for checking the elements of the profile when machining them.

The auxiliary templets are made simple in design (so as to serve not more than two elements of the profile to be checked), since making a complex templet will involve, in turn, new templets. The working elements of auxiliary templets are measured by all-purpose measuring tools.

Figure 157*a* offers an example of checking up a complex component by a depth gauge with the aid of auxiliary templets. The depth gauge is provided with a lift-and-turn bar and movable frames with a changeable set of auxiliary templets on them.

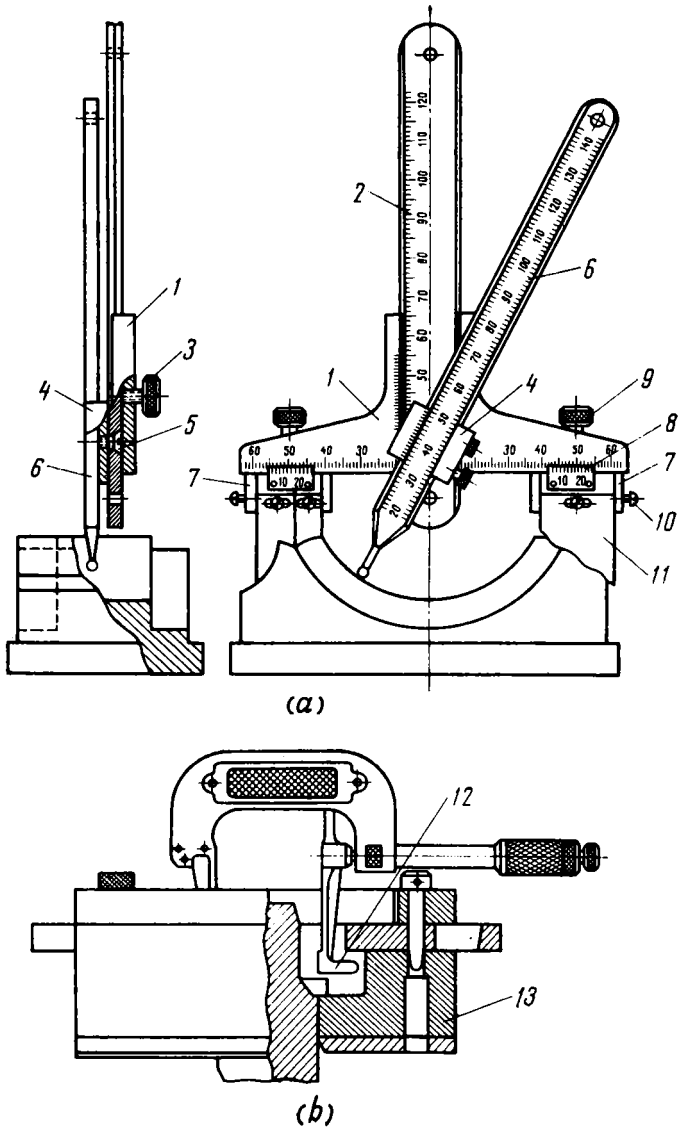


Fig. 157. Depth gauge (*a*) and inside micrometer (*b*) of special designs

1—beam; *2*—slide with scale; *3*, *5*, *9*, *10*—screws; *4*—frame; *6*—bar; *7*—frame; *8*—vernier; *11*—changeable auxiliary templets; *12*—changeable jaws; *13*—die

Travelling over beam *1* is slide *2* (with a scale) locked where required by screw *3*. The slide is connected with frame *4* by screw *5*. Frame *4* has a slot for the travel of scale bar *6* with a ball-type tip. Beam *1* also has a slot for the travel of frames *7* with vernier *8*, which are locked where required by screw *9*. The frames carry shaped changeable auxiliary templets *11* attached to them by screws *10*. They serve for checking up the profile in difficult-of-access places.

If one needs to measure the clearance between the punch and die in the assembly, it is good to fill up this clearance with easy-moulding composition, for instance, quick-setting plastics, precision-die casting composition, molten mixture of potassium and sodium nitrate, etc.

To measure the sizes in difficult-of-access places use is made of special-purpose measuring tools. For instance, a micrometer with extended measuring jaws *12* (Fig. 157*b*) can measure the distance between the recesses of split moulding die *13*.

17.5. Finishing Methods for Working Surfaces of Moulds

To bring the surfaces to high finish, the moulding surfaces are lapped and polished.

Lapping is applied to flat and shaped inserts, punches, die ports of the moulds, if the shape of these components allows lapping. The work is done on a plate or by a profile lap.

When lapping small-size pieces on the plate, they should be held firm in place by auxiliary blocks ground at an angle of 90° (Fig. 158*a*). Block *1* is placed on lapping plate *2* and workpiece *3* is forced against it, the lapping operation covering both the block and the workpiece. This keeps the workpiece dead vertically when lapping and protects its working edges from overlapping.

Figure 158*b* describes a lapping method applied to the moulding surface of die *4*, providing an angle of α which is a draft angle to facilitate the removal of the moulded article. The standard value of α is 15-30′. To properly guide lap *6* over the angle α, the benchman uses vice *7*

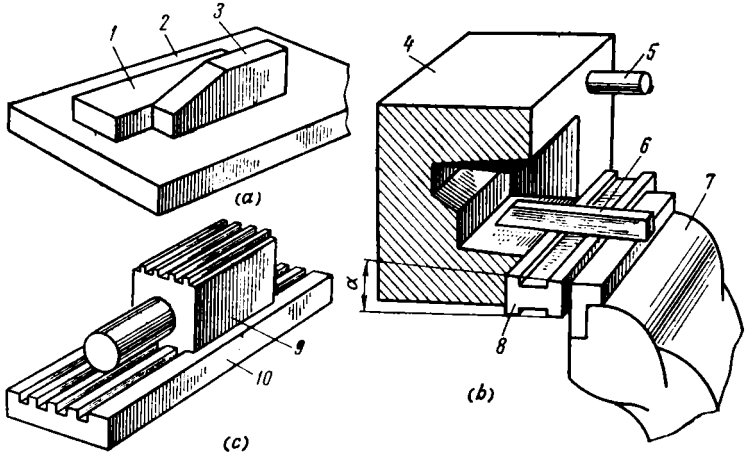


Fig. 158. Finishing methods for hardened mould components
(*a*) lapping by the use of auxiliary blocks; (*b*) providing draft while bench fitting the die; (*c*) finishing shaped inserts; *1*—block; *2*—lapping plate; *3*—workpiece; *4*—die; *5*—pin; *6*—lap; *7*—vice; *8*—plate; *9*—insert; *10*—ribbed lap

to clamp die *4* with plate *8* whose surface was previously ground to the same angle. When lapping, the lap is forced against the bevelled surface of the plate obtaining, thus, the required angle in the die. Plate *8* is mounted with respect to the die port to the gauge blocks using pin *5* mounted in the holes for guide posts.

This method is applied when making precision dies where a wrong draft angle may cause rejection. Plate *8* is made of hardened steel. Since the working surface of plate *8* wears out due to the action of the abrasive tools, it should be ground from time to time.

When lapping the ribbed surface of shaped insert *9*, one can use special lap *10* whose working surface has grooves (Fig. 158*c*). The application of such a lap considerably saves labour to be spent on lapping the slots and results in obtaining the dead straight bottom of the grooves with their accurate positioning in a common plane. The external sizes of the inserts are ground and, then, lapped on a

standard lapping plate. However, the lap should have the slots accurately corresponding to the article slots. If this is not so, the efficiency will be lower even as compared to applying a conventional lap for each slot.

It is not seldom that while extending the exacting requirements to the surface finish of the moulding components, considerable deviations from their true geometical form and specified sizes are tolerated. This refers to the moulds for making non-critical articles. In such cases lapping proves too expensive and polishing alone is considered enough. If the surface of the moulding dies and punches is complex, the application of laps is difficult or impossible, and the required surface finish is achieved by polishing.

Polishing can be done by power or manually. The former method involves application of lathe and drilling machines as well as power tools, that is pneumatic and electric grinding machines.

17.6. Assembly, Testing, and Adjusting of Moulds

If one expects the moulds to operate reliably, he should accurately fit all the components to one another. If the clearances are larger than permitted, the plastics will get into them sticking onto the components and causing scores on the friction surfaces, hence faults and rapid wear of the moulds. Special care should be taken when assembling the moulds with many cores of a small cross section. The misalignment of movable components in such moulds results in broken cores.

The assembly will be easy provided the pieces to be assembled have been properly made and machined from the common datum surfaces. When machining and filing the workpieces, it is a frequent practice to use the holes for guide posts as processing datum surfaces, such holes being made on jig-boring machines to a high degree of accuracy.

The mould will be easily assembled if the benchman, who dealt with the ports in punch holder *1* (Fig. 159), die *2*, stripper plate *3* and core holder *4*, mounted the work to the gauge blocks with respect to holes *5* for guide posts.

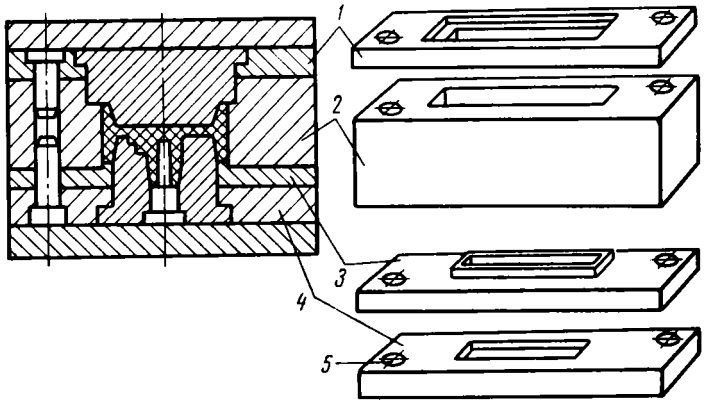


Fig. 159. Fitting main components to one another in loose compression mould

1—punch holder; *2*—die; *3*—stripper plate; *4*—core holder; *5*—holes for guide posts

The other structural members of the mould can also act as datum surfaces; for instance, two adjacent sides and the angle between them. In this case the pieces of assembly should have the correct geometry of the datum sides and the angle.

The ready moulds to be handed over for service should be tested, i.e., a trial batch of articles is moulded in such moulds. The test is necessary to see whether the articles comply with the drawing, the structural members of the mould are reliable, the moulding cavity is adequately filled. In the moulds for intricately-shaped articles it is often necessary to additionally treat the gating. The corrections in the gating are made proceeding from the tests according to the instructions made by the manufacturing engineer and designer. The tests may also reveal the necessity for correcting the ejector arrangement.

The quality of articles allows judgement not only on the finish of the moulding cavity but also upon the assembly of the mould. The faults detected during the tests should be remedied, the mould tested again and, then, sent to the store together with the moulded article.

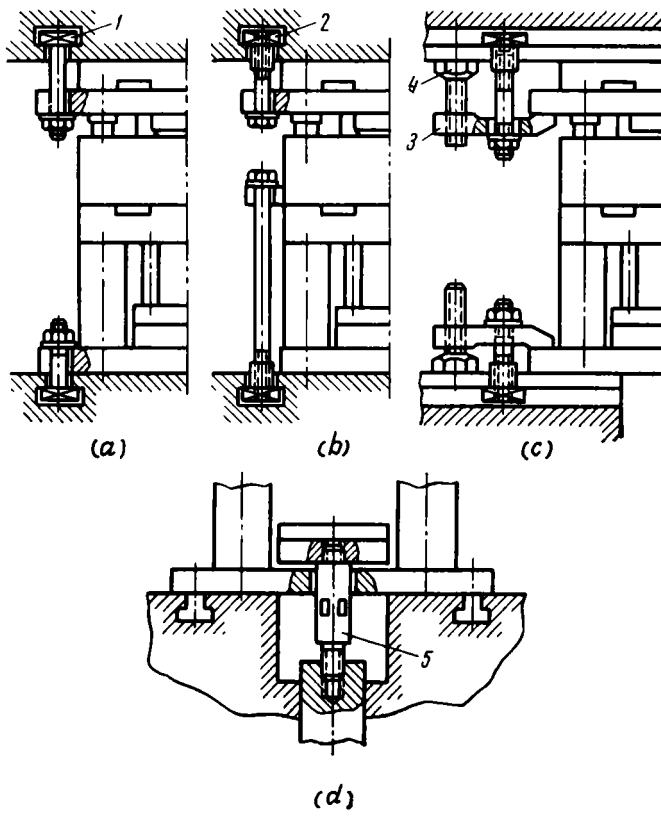


Fig. 160. Attachment of moulds to press
1 square-headed bolt; *2*—threaded insert; *3*—tack; *4*—rests; *5*—adapter pin

When testing the moulds it is very important how it was mounted and secured in the press or on the injection machine. The moulds are usually mounted in the presses or on the machines by adjusters. The adjusters test them in the presence of the manufacturing fitter.

The most wide-spread methods for attachment of fixed moulds are shown in Fig. 160. The method described in Fig. 160*a* is based on securing the lower plate and punch

holder by square-headed bolts *1*, the lower plate and punch holder having lugs matching the slots on the press plates. The method of attachment described in Fig. 160*b* is based on using lugs in the die. This allows additional adjusting of all the plates and other mould components when tightening the bolts up. To protect the plate slots when tightening up bolts *1*, use is made of threaded inserts *2*.

There is also a method for securing the mould by tacks (Fig. 160*c*). Tacks *3* are mounted at the required height using adjustable rests *4*. The tacks make it unnecessary to accurately match the lugs of the mould and the slots of the press plate, which allows the mould to be reset from one press to another differing in the location of their fastening slots.

The ejector arrangement of the mould and press pusher are interconnected by different adapters. Fig. 160*d* shows the connection by means of adapter pin *5*.

To facilitate the attachment of transfer moulds on the plates of the horizontal automatic machines for thermoplastics, provision is made of special mould-centering holes serving as datum surface. The ejector arrangement of transfer moulds has no permanent connection with the ejector of the automatic machine for thermoplastics, which makes the mounting easier.

17.7. Troubles in Maintenance of Moulds

Whether the mould is reliable in operation largely depends on how the mould is mounted in the press and how accurately its movable parts are assembled. The properly mounted and secured mould is expected to close with no jerks or shocks and to be freely unclamped. The guide posts, ejectors, and other friction parts of the mould should be oiled. With no lubricant on friction surfaces there appear scores, the unclamping and the ejection of articles become difficult.

If the mould is difficult to unclamp or the article will not go out, never use jimmies, sledge hammers, etc. These troubles are usually caused by misalignment of the mounted mould or its loose attachment. The movable parts can also be jammed or scored by plastics flown into the clearances

between the mating movable parts of the mould. Each moulding operation should be followed by compressed-air scavenging and the flash stuck to the punches, dies, guide bushes, and ejectors should be rèmoved.

In loose moulds the guide and working components are more frequently scored than in fixed ones. When using a loose mould, the punch is aligned with respect to the die before each moulding operation. This may often result in wrong alignment of the two halves and is the main cause of shorter life of loose moulds as compared to fixed ones.

The nature of wear of the mould working parts depends on its design.

In compression moulds the first to wear are the loading chamber of the die and the punch due to mutual friction when the mould is pressure-closed. This is due to the fact that the plastics getting into the clearance between the vertical walls of the punch and die make their surfaces abrade, which, in turn, gradually causes notches and scratches. In further operation the mutual friction of surfaces (even when they have fine notches) develops deep scratches and scores. This follows by the jamming of the mould when unclamping it and may finally lead to breakdown.

The most loaded components of compression moulds are guide posts and bushes. During moulding, the nonuniform distribution of the batched material in the loading chamber produces a lateral force acting against the punch and tending to shift it with respect to the die. This force is received by guide posts and bushes which maintain the correct position of the punch but this leads to their high and uneven wear, as well as to surface scores. Untimely repair or replacement of posts causes breakdown of moulds.

In transfer moulds the first to wear is the gating and the cores arranged opposite the inlet of plastics into the moulding cavity. When travelling at high speed over the gating channels the plastics gradually wears out their surface, enlarging, thus, the inlet opening and sealing of the sprues when the mould is unclamped or the article is removed. The sealing is due to damaged layer of chrome. When the inlet opening of the gating is, of necessity, to be arranged opposite the cores, they receive the strongest impact produced by the plastics jet and rapidly wear, de-

form, and even break. The cores for moulding the holes of small cross section are subject to extremely rapid wear. The badly worn cores are the cause of wrong sizes of articles.

The degree, to which the working surfaces of the mould components wear, depends first on the filler of plastics. Mineral filler, such as quartz flour or mica, wears the components worst, these fillers being used for making plastics of higher dielectric properties. Heavy wear is also caused by some moulding powders.

Transfer moulds for thermoplastics which often employ no fillers are of much longer life.

17.8. Disassembly of Moulds and Assigning the Type of Repair

All types of moulds get worn during work (wear of chrome plating, notches, hollows, dents, etc.). Under mass production of moulds, as well as of other manufacturing equipment, a schedule of maintenance repairs and overhauls is usually made up.

The aim of the maintenance repair is to do away with minor faults on the polished surface of the moulding components and to restore chrome plating. For the maintenance repair the mould is disassembled only partially, that is only the punch and die are removed. For the overhaul not only the punch and the die are removed for replacement, but also the mould units are disassembled for repair or replacement of worn components.

When sending the mould for repair, it is quite necessary to send also the articles moulded last. The latter will allow detection of faulty elements of the mould. If there is dullness, instead of lustre, on the article surface, this means that the moulding surfaces are faulty and the surface finish is inadequate. It is rather easy to find the mould parts requiring repair. On the other hand, dull surface may result from the causes having nothing to do with the mould. There are different troubles affecting the article surface which can be detected only by the manufacturing engineer who can also suggest the remedy. Such troubles include higher content of moisture in the plastics, inadequate mo-

ulding pressure, inadequate batch, etc. The cracked surface testifies to faulty ejectors or inaccuracies in the assembly of moulds. For instance, cracks may be due to the misaligned punch in the punch holder.

Periodical check up of the sizes of the articles makes it possible to take timely measures to remedy the mould faults. How far and in what way the sizes deviate from those specified should be taken as an indication of the fault. The variations in the thickness of walls reveal heavy wear of guide posts and bushes, as well as other locking elements.

Whether the mould wants repair can also be found by how reliable it is in operation. Thus, difficult ejection of articles, sealing of its parts are indications of poor surface finish of the mould. When unclamping the mould the same fault may detain the article on the side where it is not to be ejected. Vibrations, jerks and creaks caused by clamping or unclamping or by operation of the ejection system mean that the mould is inaccurately mounted in the press, or the guiding and ejecting components are poorly manufactured and assembled.

17.9. How to Recondition Worn Components

The faults on the surface due to mutual friction of structural members of the mould (guide posts and bushes, loading chamber and the locking part of the punch) can be remedied by bench trimming and polishing. The same operations performed upon the moulding components in repair prove more difficult since the volume of stock in this case influences the size of the article. To recondition the surface finish of the worn area of the moulding component the mould is sent to the electroplating shop where they remove chrome plating from the damaged spot and lap or polish it; then this spot is chrome-plated again and finally polished. In this type of repair the removed stock is hundredths of a millimetre. However, the reconditioning of the moulding surface finish is to be done frequently, especially when processing the plastics with mineral fillers. For longer life of the mould the articles should be made with looser dimensional tolerances. Looser tolerances

allow a great number of repair. This contributes to higher resistance of the mould and cuts the cost of articles.

The moulding components should be repaired as hardened, without annealing them. Annealing with subsequent hardening often deforms the component involving, thus, more complicated repair or leads to rejection of the mould.

Some of the moulding components which are subject to excessive wear are replaced during repair. For instance, a common practice is to make some spare fine cores and sprue bushes which come in handy during repair. For easier repairing the shaped moulding components are made sectional, if their members are not strong enough and can break during moulding. It is quite reasonable because it is easier to replace a broken piece than to make a new component. The core also can be made sectional which facilitates replacement of its fine part that is liable to break.

Deep partial faults (hollows, chipped-off spots) on the surface of large-size punches and dies can be remedied by welding up or hard-facing. In some cases, a hole can be bored at the damaged spot and an insert is secured in it, the external part of the insert being of the shape of the surface to be remedied.

17.10. Safety Rules

The fitter who made the mould takes part in its testing and helps the adjuster of the presses in mounting it in the press or on the injection machine.

Mounting of loose moulds differs from mounting of fixed ones. The former procedure is not complicate. The mould should be placed in the middle of the press bed. When mounting several loose moulds at a time, it is necessary to see to that they are of equal height and positioned as close to the centre of the bed as possible. If this is not observed, the movable platen of the press may get misaligned with the resulting rejection of articles. Loose moulds should be provided with handles.

Fixed moulds should have eye-bolts for their connection with the hoist slings.

Injection moulds for thermoplastics should be secured by tie studs along the parting line when handling, mount-

ing, and dismantling them. The moulds should be reliably attached to the platens (at least six bolts for each flange). Attachment by four bolts can be tolerated in some special, rare, cases.

Prior to mounting and adjusting the mould for test it is necessary to check up the condition of the press by lowering and lifting the main and ejection rams, the press electrical wiring, the condition of tools engaged, the thread of the ejection ram and the ejection shank. When adjusting the mould, switch off the heater.

Chapter 18

Metal Die Casting

18.1. Essentials of the Process

In injection moulding the molten metal is fed into a steel loose mould under the pressure of several hundred atmospheres, which allows the mould to be adequately filled up and the castings of Class 3-5 accuracy to be obtained.

The molten metal is fed with the aid of piston actuated by the hydraulic drive on the machines with a horizontal or vertical moulding chamber. The latter can be either hot or cold.

Figure 161 shows a diagram of a die casting process. Diagram *I* showing the operation of the horizontal-chamber machine describes four successive positions of moulding piston *1* and die *2* with one movable core *3* which is removed from casting *5* by a special device (not shown in the figure). When the working cycle begins (Fig. 161*a*), the two dies are closed with the core being in the working position. Moulding piston *1* is in the extreme right-hand position. The metal is poured into casting chamber *4* from a ladle.

Moulding piston *1* (Fig. 161*b*) moves to the left and forces the metal into the cavity *A* of die *2*. The movable die (the left one) moves away from the fixed (the right one) carrying

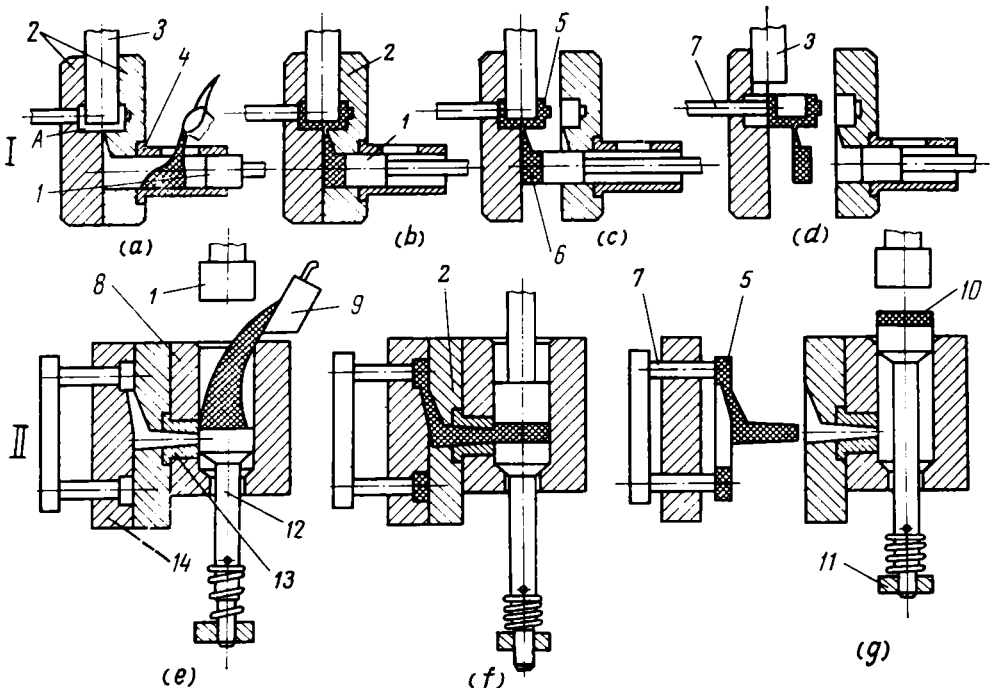


Fig. 161. Diagram of machine casting

I—horizontal-chamber machine; *II*—vertical-chamber machine; *1*—moulding piston; *2*—dies; *3*—core; *4*—horizontal chamber; *5*—castings; *6*—sprue; *7*—ejectors; *8*—vertical chamber; *9*—ladle; *10*—excessive metal; *11*—pusher; *12*—return piston; *13*—adapter; *14*—movable plate

casting *5* (Fig. 161*c*) with it. The piston goes on moving to the left and ejects sprue *6*, connected with the casting, out of the fixed die. Core *3* is completely removed from the casting (Fig. 161*d*). The movable die stops and ejector *7* extends from it to eject the casting. The piston returns then to the right, into its initial position. The working cycle is now over and starts again to produce the next casting.

Diagram *II* (Fig. 161*e*, *f*, *g*) shows the process of filling the die in the die-casting machine having a vertical chamber.

Die casting is advantageous in that it yields castings of high dimensional accuracy and good relief contour; it is also very efficient. This technique is the only one which allows thin-walled articles to be obtained. For instance, small aluminium or zinc pieces from 10 to 30 grams in mass can be cast with walls from 0.5 to 0.8 millimetre in thickness.

The surface finish of the casting depends upon that of the casting die and its time of service. If the casting die is polished or finish-ground, the castings can be obtained with Class 7-8 finish. With the wear of dies their surface finish deteriorates.

The pieces obtained by die casting are distinguished by high dimensional accuracy as compared with castings made by other techniques and, therefore, require no further machining. The latter is usually applied for making fine holes, threads, and occasionally, for machining support and mating surfaces. Machining allowance is left as small as possible (up to 1 millimetre) since the die castings can be porous and have fine blisters at some distance from the surface.

Die casting finds a wide application in machine building, tool engineering, and other industries. This technique is used for casting parts of different household appliances and machines (vacuum cleaners, washing machines, fans, refrigerators, etc.), camera casings, etc.

Die casting, too, has its disadvantages: castings are porous, which detracts from mechanical strength of parts (due to intensive stirring of metal with air under a rapid filling up of the die); only a few alloys can be used for making good castings by this technique; the overall dimensions

and power of the available casting machines allow production of castings which are not very heavy or large.

Not all the metals lend themselves well for making die castings. Among those which are not suitable for this purpose are bronze alloys. Use can mainly be made of zinc, magnesium, aluminium, and copper alloys.

Die casting of ferrous metals (steel, cast iron) is still being experimented. The main obstacle in using ferrous metals for die castings consists in poor strength of dies.

18.2. Die-Casting Machines

Die casting of non-ferrous alloys can be performed in either cold-chamber or hot-chamber machines.

The technique under which the molten metal is fed from the chamber heated up to the temperature of the molten metal is referred to as *hot-chamber die casting*.

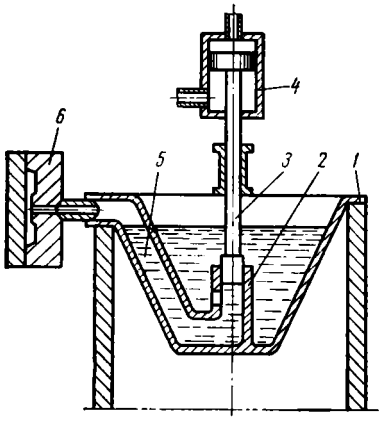


Fig. 162. Diagram of hot-chamber die-casting machine

1—holding furnace; *2*—chamber; *3*—ram; *4*—cylinder; *5*—inlet channel; *6*—die

Figure 162 presents a diagram of a hot-chamber machine. Holding furnace *1* made in common with chamber *2* is filled in with the alloy. Ram *3* connected, via the rod, with the piston of a pneumatic (or hydraulic) cylinder *4* presses against the alloy. Under the pressure of ram the alloy passes through inlet channel *5* which connects the chamber with die *6* and fills in the working cavity of the die.

The hot-chamber machines are more efficient than the cold-chamber ones. The hot-chamber machines are used for making castings in lead-tin and zinc or other low-melting point alloys. The higher-melting-point alloys (aluminium- and copper-based) are cast on the cold-chamber machines.

Such machines are preferred because the ram and the chamber of the hot-chamber machine are subject to rapid wear due to hot medium.

The casting technique according to which the batches of molten metal are first fed to a cold chamber and then forced by the ram into the die is referred to as *cold-chamber die casting*.

This technique of casting is implemented on the machines with a vertical or horizontal cold chamber, the latter being shown in Fig. 161, diagram *II*.

Let us consider this machine again (see page 396). At the beginning of the casting cycle (position *e*) with piston *1* up, the molten metal is fed into chamber *8* from ladle *9*. Return piston *12* is held up by the spring and shuts the opening of sprue adapter *13*. This prevents the metal from getting into the die by gravity flow, under no pressure.

When descending (position *f*), piston *1* presses against the metal and moves return piston *12* forcing a batch of metal into the casting cavity of the die through the sprue channels.

After the holding period, piston *1* ascends into its initial position (position *g*), the return piston actuated by pusher *11* removes excessive metal *10* from the chamber whereas casting *5* is ejected out of the die by ejector *7* when movable plate *14* goes to the left.

Machines with horizontal cold chambers have some advantages as compared to the vertical-chamber machines in the following respects:

(1) short travel of metal from the chamber into the die cavity with no turn at the right angle, which allows the metal to fill up the die under higher pressure;

(2) shorter working cycle since there is no need to remove excessive metal; the latter is pushed in the direction of casting at the time when the die opens;

(3) faster opening of the die and removal of the casting with lesser upset of the die projections by metal when the casting cools off; this also allows more complex articles to be cast.

The design of horizontal-chamber casting machine is shown in Fig. 163.

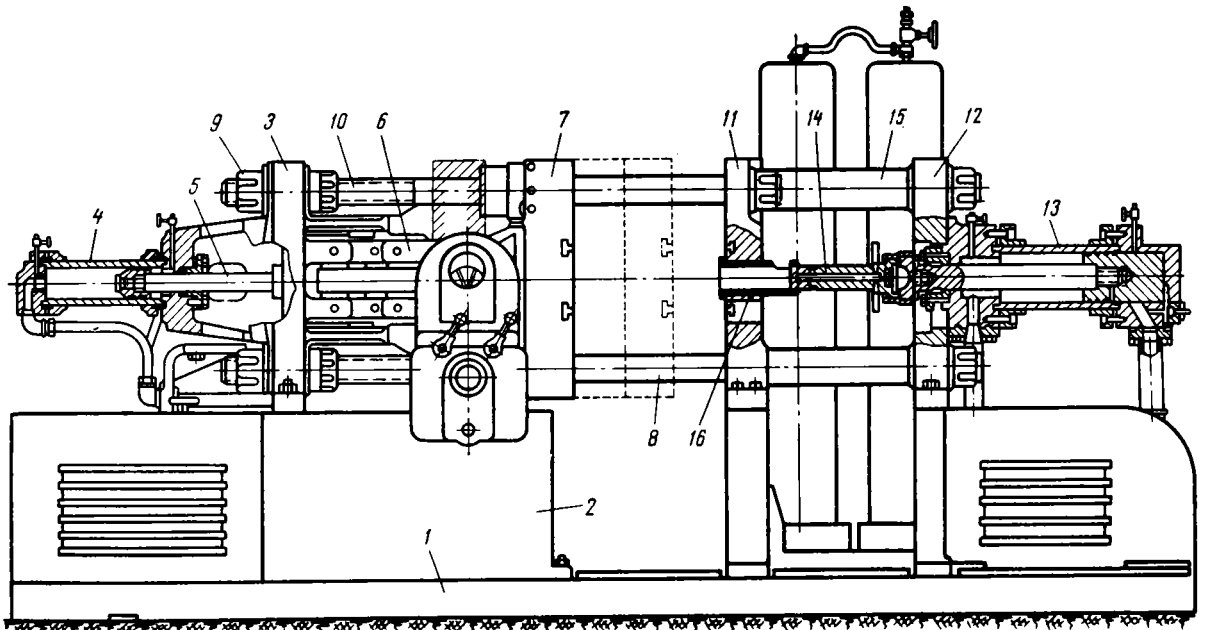


Fig. 163. Design of horizontal cold-chamber die-casting machine

1—foundation plate; *2*—bed; *3*—vertical plate; *4*—hold-down cylinder; *5*—piston and rod; *6*—hold-down mechanism; *7*—movable platen; *8*—posts; *9*—nuts; *10*—ties; *11*, *12*—R. H. unit plates; *13*—casting cylinder; *14*—casting piston; *15*—ties; *16*—chamber

The machine comprises two horizontal units: the left-hand and right-hand ones. The left-hand unit opens and closes the die and holds it clamped when the metal is forced in. The left-hand unit accommodates the ejector to remove the casting when the die opens. The right-hand unit is designed for forcing the metal in the die cavity and removing the excessive metal out of the chamber.

The two units are mounted on foundation plate *1*. Attached to bed *2* of the left-hand unit lying on plate *1* is vertical plate *3* with hydraulic cylinder *4*. Piston and rod *5* of this cylinder are connected with lever-and-hinge or link mechanism *6* which precludes the departure of the movable platen when the metal is forced in. Link mechanism *6* is joined to movable platen *7*. When rod *5* travels, platen *7* moves over posts *8*. To mount the dies of different height the link mechanism is adjusted by nuts *9* and ties *10*. Platen *7* accommodates the left-hand movable die (not shown in the figure).

Two vertical plates *11* and *12* of the right-hand unit joined by ties *15* are mounted on foundation plate *1*. Plate *11* accommodates the stationary die, plate *12* serving for attachment of cylinder *13* of casting piston *14*. Casting chamber *16* with the casting piston is between plates *11* and *12*. When the piston moves to the left, the metal is force-fed out of the chamber into the die cavity.

18.3. Design of Dies and Their Basic Components

The design of dies for casting non-ferrous metals has much in common with that of dies for transfer moulds to deal with thermoplastics. Figure 164 shows such a die. The right-hand (stationary) half of the die having a special hole is placed on the sprue bushing (chamber) of the casting machine and bolted to the stationary plate. The left-hand (movable) half of the die is bolted to the movable platen. The die can be opened along the parting line so as to freely remove the casting by moving the platen to the left.

When deciding upon the parting line and the arrangement of the generating components with respect to the

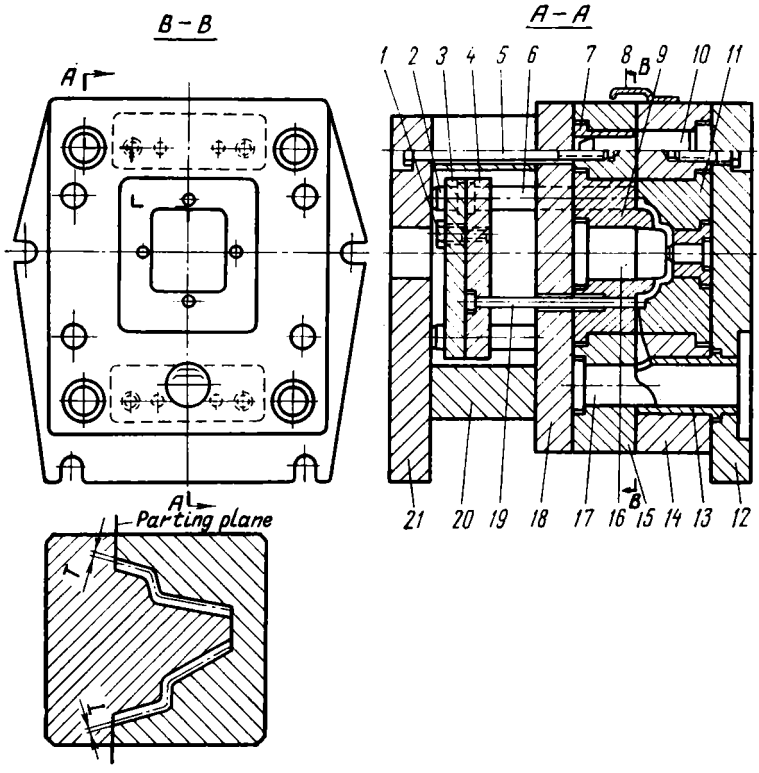


Fig. 164. Standard casting die for non-ferrous metals and diagram showing how casting shrinks in die

1—screws; *2*—rests; *3*, *4*, *14*—plates; *5*—bolts; *6*—dowels; *7*—guide bushes; *8*—shield; *9*—bushing (insert); *10*—guide posts; *11*—insert; *12*, *18*—unattached plates; *13*—adapter; *15*—case; *16*—core; *17*—spreader; *19*—ejectors; *20*—posts; *21*—attachment plate

parting plane, it is necessary to account for the shrinkage of metal in the die.

The shrinking casting upsets the die projections which are in the generating cavity, these projections forming the internal contours of the casting. As a result the casting parts from the walls by the value of shrinkage *T* (see Fig. 164, bottom).

The shrinkage of the alloy governs the position of the casting in the die after it is opened, the casting always being in the die half with many projections generating the internal outlines. It is in this die half that the ejectors of the castings are arranged.

For spare use of alloy steel and convenience in making and repair of dies, the part which contacts the molten alloy is often made as insert or lining *11*. The component of the die subject to the heaviest wear is the sprue channel through which the molten alloy is pressure-fed from the machine chamber into the die cavity. The sprue channel is provided with adapter *13* made of alloy steel. Generating insert *11* and the adapter are mounted and secured in a common case, i.e., plate *14*. An accurate locking of the movable and stationary dies with respect to each other is achieved by means of guide posts *10*. To protect the operator from splashes spattering along the parting plane when molten metal is forced into the die, plate *14* has shield *8*. If necessary the same plate can be provided with channels for water to cool the stationary die.

Unattached plate *12* serves as a support for the inserts, guide posts, and other members secured in plate *14*. The unattached plate has a recess for a shoulder of the machine chamber and threaded holes or slots for securing the stationary die to the machine.

The left-hand die is attached to the movable platen of the machine. This part of the die is provided with an ejection mechanism, therefore, the parting of the die and its design are to retain the casting in the die after it is opened. Most of the projections and cores generating the internal contours are provided in the movable die. The working cavity of the left-hand die is usually made as bushing or insert *9*.

To guide the jet of a molten metal, pressure-fed into the die cavity, use is made of spreader *17*. With its working part the spreader enters the adapter to form together with it a sprue channel of the required section. The generating insert and the spreader are mounted in case *15*. To prolong the case life and to maintain constant direction, provision is made of guide bushes *7* which are replaced with wear.

To form holes and depressions in the casting cores are

used. Depending upon the shape of the casting and the design of the die, the cores can be mounted in the generating inserts, cases, platens, and ejector plates. Core *16* with its working part perpendicular to the die parting plane does not hinder the removal of the die out of the die cavity. The cores of this type are usually placed as stationary ones. The cores with their working part parallel to the parting plane should be withdrawn before the casting is removed from the die. They are made movable for which purpose the die is provided with core pulls. The pulls can be manual, semi-automatic, and automatic. When making the internal cavities in places inaccessible for both the stationary and movable cores, the die makers resort to collapsible cores which can be removed from the die together with the casting, then separated from it outside the machine by pulling devices and placed in the die again prior to metal pouring.

The insert, cores, and bushes mounted in case *15* are forced against it by unattached plate *18*. The case and unattached plate are secured by bolts *5* to the foundation which can be either of one-piece (cast) or sectional design, in the latter case it is comprised of posts *20* and attachment plate *21*. The foundation has holes for securing it to the movable platen of the machine.

The casting is removed from the movable dies by ejectors *19*. They can be simple-shaped (round, rectangular, tubular) or intricately-shaped (reproducing the contours of the casting). The ejectors are arranged where the casting upsets the projections of the die with the maximum force, i.e., where the casting is most difficult to remove from the die.

In the design under consideration the ejectors are provided in plates *3* and *4* secured by screws *1*. These plates are connected with the ejector drive which can be of a manual or power type. The ejectors are set in motion only after the die is opened and all the movable cores are removed from it, their return into the initial position is accomplished when the die closes by means of cylindrical dowels *6* fixed in plates *3* and *4* and reaching the parting plane. Dowels *6* are referred to as counter ejectors. Plates *3* and *4* accommodate rests *2* which ensure stable position for the ejectors

at the moment of the hydraulic hit when forcing the molten alloy into the die.

The die should have a certain temperature to suit that of the alloy used for casting, therefore adequate coolers should be designed in the die. Sharp edges and projections can be cooled only by means of an air jet. More rapid cooling can be achieved by water. The water ducts are spaced not nearer than 10 millimetres from the walls of the die working cavity to avoid cracks. A usual practice is to make ducts in the plates accommodating the dies generating the external contour of the casting since the internal surfaces heat more intensively than the external ones. The thickness of the working parts bears considerably upon the die temperature. The thin-walled dies are heated quickly, but are more liable to temperature variations. The thick-walled dies are heated through more slowly but keep the working temperature longer. This explains why the thin-walled dies are avoided.

A good cooling medium is water circulating in a tube built in the unattached plate and contacting generating insert (Fig. 165*a*). In unattached plate *1* which is beneath

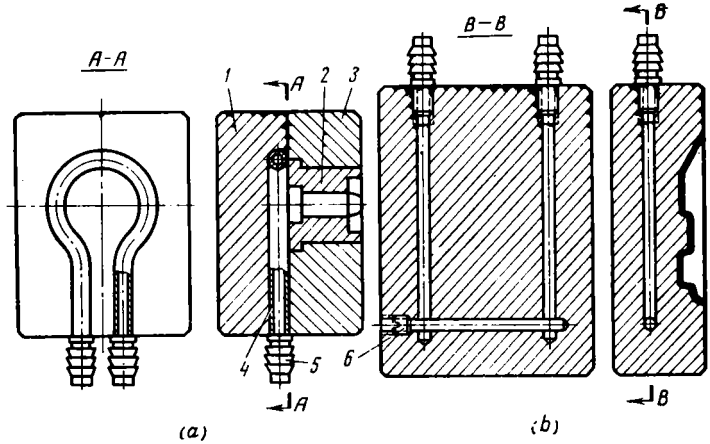


Fig. 165. Devices for die cooling

1—unattached plate; *2*—insert; *3*—movable plate; *4*—tube; *5*—union; *6*—plug

insert *2* and movable plate *3*, a slot is made for tube *4* with unions *5* welded to it. Water is delivered through the rubber tubes connected to the water pipeline and sewerage. Cooling by flowing water is the best method for obtaining constant temperature, especially in small-size dies.

The die and punch plates (Fig. 165*b*) are cooled by water passing through the ducts drilled inside them. For convenience of manufacture the ducts are drilled from both sides and then plugged with threaded plug *6* from one side.

Chapter 19

Manufacture and Repair of Dies for Casting Metal

19.1. General Requirements

All the parts of the die should be carefully fitted if one expects the die to operate reliably. If the clearances exceed the permissible ones, the molten metal can fill them in and stick there causing scores, deterioration of the quality of some areas on the die surface, and rapid wear of the die.

The parting plane of the die should have no scores or dents. The faulty areas on the parting plane allow metal to stick, hence the die does not close tightly enough.

The sizes of the die cavity should exceed the casting sizes by the value of the alloy shrinkage. The manufacturing accuracy of the generating die depends on how accurately the casting is made. A standard practice is to make the generating parts of the die complying with Class 3 accuracy.

The locating sizes of the mating parts are to comply with Class 2-3 accuracy. Since the clearance between the parts varies when the die is heated, the locating places of movable parts should be made to the running fit.

The surface of the generating die should be not worse than Class 8 finish. The higher the surface finish of the die,

the better the surface of the castings and the lower the probability of the metal sticking to the die.

According to their purpose, the units, components, and mechanisms of the dies can be classified into three main groups: generating components, structural components, and the mechanisms of the die.

Each group is expected to meet special requirements from the standpoint of their purpose and the nature of their performance. For instance, the generating components should withstand well the impacts of the hydraulic system and the influence exerted by the molten alloy. To obtain a good-quality casting, they should be made to a high degree of precision (usually to Class 3 accuracy) and to Class 8-9 surface finish.

The structural components should be strong; they should not deform when they are imparted the force by the working components, ensure accurate mutual positioning of the moving parts when the die operates, and be convenient for good attachment of the die on the machine.

The mechanisms serve for normal operation of all the moving parts under elevated temperature without misalignment or jamming, as well as for providing their stable position when the molten alloy is fed in.

19.2. Materials for Making Die Components

Since die casting is accomplished at elevated temperatures and alternating heating and cooling, the material the die is made of is subject to heavy working conditions. The material for dies is to keep good hardness, retain high impact and fatigue resistance; its thermal expansion coefficient is to be low.

The grades of steel for dies are so selected as to suit the alloy being used and the working conditions of the dies. All the components of the die contacting the molten metal are made from the heat-treated alloy tool steel. The friction components working out of touch with the molten metal are made from carbon tool steel.

Table 12 gives the grades of steel most frequently applied for manufacturing the die components.

Table 12

Grades of Steel Used for Making Components of Dies

Component	Cast alloy	Steel grade	Hardness R_C
Generating components	Zinc- and copper-based alloys	5XHM, 5XГM, 3X2B8, 4X8B2	44-48
	Aluminium- and magnesium-based alloys	3X2B8, 4X8B2, 4XB2C, 5XB2C	48-52
Platens for dies and punches (cases)	All alloys	Steel 45, 50	28-32
Unattached plates, ejectors, etc.	Same	Steel 35	
Bushes and guide posts, wedges	Same	У8А	46-50
Support plates, counter pushers	Same	Steel 45, 50	40-45

19.3. Making and Assembly of Dies

Casting dies are made using the same bench techniques, checking methods, and tools as used in making moulds for processing plastics (see Chapter 17). At present the die casting technique is used for making intricately-shaped castings, this calling for application of not only general-purpose but also special machine tools, such as profile grinding and jig grinding machines.

Electrophysical machining methods have also gained a wide application in making complex dies. These are electrospark, electro-erosion, and ultrasonic techniques.

Assembly of dies for casting non-ferrous metals is much the same as assembly of the fixed moulds for plastics. The assembly fitters of casting dies should pay special attention when fitting the movable parts of the dies. They are to be

adequately tight-fitted so that the metal has no access between the joints, but without any grips or jamming. It should be borne in mind that the degree of tightness of fitted components when cold differs from that in the process of casting. Therefore, the die components which are movable in a cold state during operation (especially when casting copper alloys) may jam one another, if the clearances between them were made regardless of the fact that different mating components heat differently. The locating places for movable components should be mounted with running fit.

19.4. Testing of Dies

The ready die is tested to see its workability and the quality of castings it produces. The gating and the arrangement of the air vents can be improved by no other way than first testing them.

Prior to testing the die, it is heated up to the working temperature so as to preclude or decrease the amount of metal flowing into the clearances of the movable components, this being done when casting the first pieces. The die is heated by electrical heaters or gas burners.

The tests allow the best possible casting conditions to be found, i.e., the pouring rate, the pressure upon the melt, and the required holding time. The main criteria are the density of castings and the quality of their surface. The tests should be supervised by an experienced foundry man.

The types of defects and their causes are numerous, which often makes it difficult to detect them. For instance, a defect of porosity over all the sections may be the result of many causes: the forcing of metal into the die is too rapid, a wrong arrangement of the air vents or they are too narrow, a wrong method of feeding the alloy into the die. The misruns, cold shuts, unnecessary edges and sharp corners also result from different faults: a drop of voltage in the mains, the forcing of metal is too slow, inadequate ventilation of the die, the alloy is too cold, the die is too cold.

During the tests, a trial batch of castings are made and their sizes are compared to those specified in the drawings.

19.5. Troubles and Their Remedies

The molten metal jet hits against the wall of the die or core and, in this way, gradually wears their surface, which detracts from the quality of the casting surface. Thus, the roughness of the casting surface depends upon the time of the die service. The die cavity finished by polishing or grinding yields the castings with Class 7-8 surface finish.

The generating cavity of the die which produced 8,000-10,000 castings of alluminium alloys develops a net of cracks ("burn wear"), which leaves a fine net-like design on the casting. Due to the interaction of the elevated temperatures the corners on the ejector faces burn out, thus leading to burred castings.

To facilitate the correction of these defects in the castings, the following measures can be taken: preventive trimming of the die cavity, application of heat-resistant materials for the die, strict observance of the conditions prescribed for the casting process.

The wear of the generating surfaces due to impacts produced by the jets of the molten metal is the most common defect occurring during the maintenance of dies.

It is not seldom that as a result of burn wear the alloy sticks to the surface of the generating components. Usually the alloy sticks where the surface finish is damaged. If the alloy sticks to the wall of the core along which the casting is ejected, then the stuck particles scratch the surface of the casting during its removal causing rejection. To avoid this, it is necessary to carefully trim and polish the damaged area of the die, otherwise the sticking will go on periodically, hence rejection.

The metal stuck to the parting plane of the die also causes troubles. This can be precluded by machining the parting planes to a high degree of finish and by keeping them in good condition during maintenance. If there are any metal particles left on the parting plane, the die will not close tightly enough, which detracts from dimensional accuracy of the casting and causes the shooting of metal into the unnecessary clearance. If the alloy particles are not removed timely from the parting plane, the surface will be too rough, causing some more sticking.

One of the common defects of the die where the molten metal is fed directly against the fine generating cores is their frequent breakdown.

The die designers do their best to prevent this, directing the flow of the metal so as to make it pass by the slim cores liable to burn out at the edges and to break.

The movable guides and locking members, i.e., posts, slide gates, inclinable guide pins, work under heavy conditions of unilateral pressure, when the metal is forced in, and at elevated temperatures of the molten metal.

The operators should keep a close eye on the condition of these members. Should even a fine drop of metal be allowed to leave, it may cause a scratch; then a deep burrow and a score will quickly result on the mating surfaces causing, in turn, the breakdown of the die members and the rejection of the die.

Another frequent trouble in the operation of dies is a breakdown of long slim pushers due to misalignment in the ejection mechanism. The usual cause of this trouble is a heavy wear of the guides in the ejection mechanism. To avoid this defect, the movable members of the ejection system should be periodically lubricated and the pushing stops on the machine duly adjusted.

A partial scab on the surface of the generating core may cause undercuts which scratch and score the castings being ejected. Similarly to burn wear, this defect comes after a long operation of the die.

19.6. Repair of Dies

The most common type of repair is that of the generating members to remedy the surface damages due to burn wear. It is very important that such repair be done timely, since microcracks due to burn wear grow rapidly and, soon it will be impossible to remove them without infringing upon the sizes of the generating cavity. It is recommended that the surface finish of the generating components be restored during the preventive repair performed after a certain number of castings have been made. The damaged surface can be repaired by grinding, lapping, and polishing. The condition of the die largely depends on the observance of the maintenance rules. Special care should be taken of the

surface finish of the die parting plane since the flash left there may cause the shooting of metal over the parting plane and its getting into the movable mechanisms of the die. Should any slight defect be detected on the parting plane, it must be ground and lapped. To facilitate these operations and to provide higher specific pressure in the closing zone of both die halves, the contact surface in the parting plane should be made smaller.

One of the ways to repair the dies is to periodically replace the parts subject to rapid wear.

The surface of the die arranged against the sprue wears rapidly. To prolong its life or to make its repair easier, it is advisable to arrange a spreader at this spot (Fig. 166). Spreader *1* changes the direction of the metal jet and relieves its blow against the opposite wall of the die. The spreader also improves the injection of metal allowing the jet to change from a round to flat cross section; this makes the flow uniform. By facilitating the working conditions of the die the spreader prolongs its life. The spreader itself is made changeable since it is subject to rapid wear. Another frequently-changed component is adapter *2* protecting the stationary plate from wear.

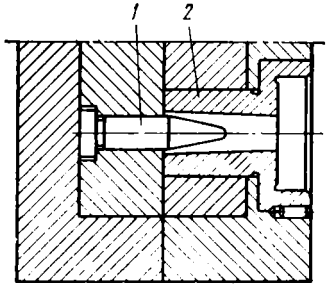


Fig. 166. Changeable components of gating system
1—spreader; *2*—adapter

The following safety rules must be observed when making and repairing the dies. When testing a die on the casting machine one should not put a cold pouring cup into the molten metal or charge cold scrap into the melting furnace to avoid the shooting of metal. It is not permitted to stand opposite the parting plane when pouring metal since the metal splashes fly in this direction if the die halves are not tight against each other. The pouring operator should use a cup with a long handle (not shorter than 1000 millimetres). Each workman operating a casting machine should be instructed in safety rules to be observed at his workplace.

Section V

JIGS AND FIXTURES

Chapter 20

Design of Jigs and Fixtures

20.1. Purpose and Classification

Jigs and fixtures are the most wide-spread type of tooling equipment. They are intended for locating and holding the workpieces, their correct orienting with respect to the tool and the working parts of the machine, as well as for properly guiding the cutting tools.

Jigs and fixtures are classified according to three basic features: the degree of their specialization, the type of machines they are mounted on, the degree of their mechanization.

As to the degree of their specialization the jigs and fixtures can be classified into:

universal jigs and fixtures used in machining different workpieces by adjusting their elements to the required size (machine vice, lathe chucks, swivel tables, indexing heads, etc.);

readjustable jigs and fixtures used in machining different workpieces; they can be further subdivided into:

(a) universal-and-sectional (special jigs and fixtures assembled from standard parts comprising a set of such jigs and fixtures);

(b) universal-readjustable jigs and fixtures with changeable standardized adjusting pieces (vice with changeable shaped cams and jaws, collet chucks with changeable cams, chucks with changeable guides, etc.); included herein are also gang accessories for machining a certain batch of workpieces; such jigs and fixtures can be provided with change-

able adjusting pieces or with constant adjusters allowing different workpieces to be machined without resetting;

special-purpose jigs and fixtures intended for machining one workpiece or a batch of workpieces similar in design and manufacture. Such jigs and fixtures are designed to suit certain machining conditions, the shape and size of workpieces with once adopted scheme of datum surfaces.

The universal and universal-sectional jigs and fixtures are normally used in single-piece and small-lot production, the universal-readjustable and special ones, in lot, large-lot, and mass production.

As to the types of machine-tools, they are used on, the jigs and fixtures are classified into lathe, milling, drilling, and other types.

As to the degree of their mechanization, jigs and fixtures are classified into those with manual and power clamps; the latter can have manual, semi-automatic, and automatic controls.

The drives for power jigs and fixtures are subdivided, according to the source of power for their actuation, into: spring, mechanical, pneumatic, hydraulic, electro-mechanical, magnetic, centrifugal-inertial, and those of combined types (the latter are spring-and-pneumatic, spring-and-hydraulic, etc.).

In designing a jig or a fixture the following requirements should be met: adherence to the rule of selecting the datum surface; provision of accurate and stable mutual position of the work and tools in machining; convenient mounting, removing, and controlling of work; unobstructed discharge of chips; constant clamping force while applying it where the work is not marred or deformed; rigid mounting of the work; safe operation; saving the work surfaces.

All jigs and fixtures employ standardized elements which can be divided into the following groups:

locating elements for properly positioning the workpiece;

clamping elements which are devices and mechanisms for securing the workpieces or moving parts of jigs and fixtures;

tool-guiding elements;

power devices for operating the clamping elements (mechanical, electrical, pneumatic, hydraulic);

bodies accommodating all the rest of the elements;
auxiliary elements for changing the position of the workpiece in jigs or fixtures with respect to the tools, for joining the elements to one another, and for adjusting their mutual positions.

20.2. Elements of Jigs and Fixtures

Locating elements. These are the elements supporting the locating surfaces of the workpieces. The system of locating elements includes rest buttons, pads, V-blocks, locating pins, as well as centering devices and the mechanisms for operating the rests.

For locating flat surfaces use is made of *rest buttons* or *pads*. For locating flat machined surfaces flat-headed rest buttons or plain pads are used (Fig. 167,*a* and *b*).

The workpiece with unmachined surface is located on buttons with spherical or knurled heads and pads with bevelled slots (Fig. 167,*c* and *d*).

Forgings and castings are occasionally machined with the aid of *adjustable rests* (Fig. 167*e*).

The rest buttons are force-fitted directly into the holes bored in the bodies or in the hardened adapter bushings pressed in the body, the pads are fastened to the body by screws.

For better stability of the work under the forces tilting or deforming it, *auxiliary* (Fig. 167*f*) or *self-adjusting* (Fig. 167*g*) *rests* are used. In the self-adjusting rests, plunger *2* is actuated by spring *1* which is brought into contact with the work; then the plunger is locked in this position by bolt *4* pressing against clamping slide block *3*.

Cylindrical surfaces are located in *locating V-blocks* (Fig. 168*a*), for locating on holes use is made of *locating pins* (Fig. 168*b*).

Housings, plates, frames, crankcases, and similar parts are often located on two cylindrical holes with parallel axes and on a flat surface perpendicular with them. In this case the workpiece is placed on two pins, one being straight and the other cut away on two sides (Fig. 168*c*). For locating on the hole and flat surface the pin is also cut away (Fig. 168*d*).

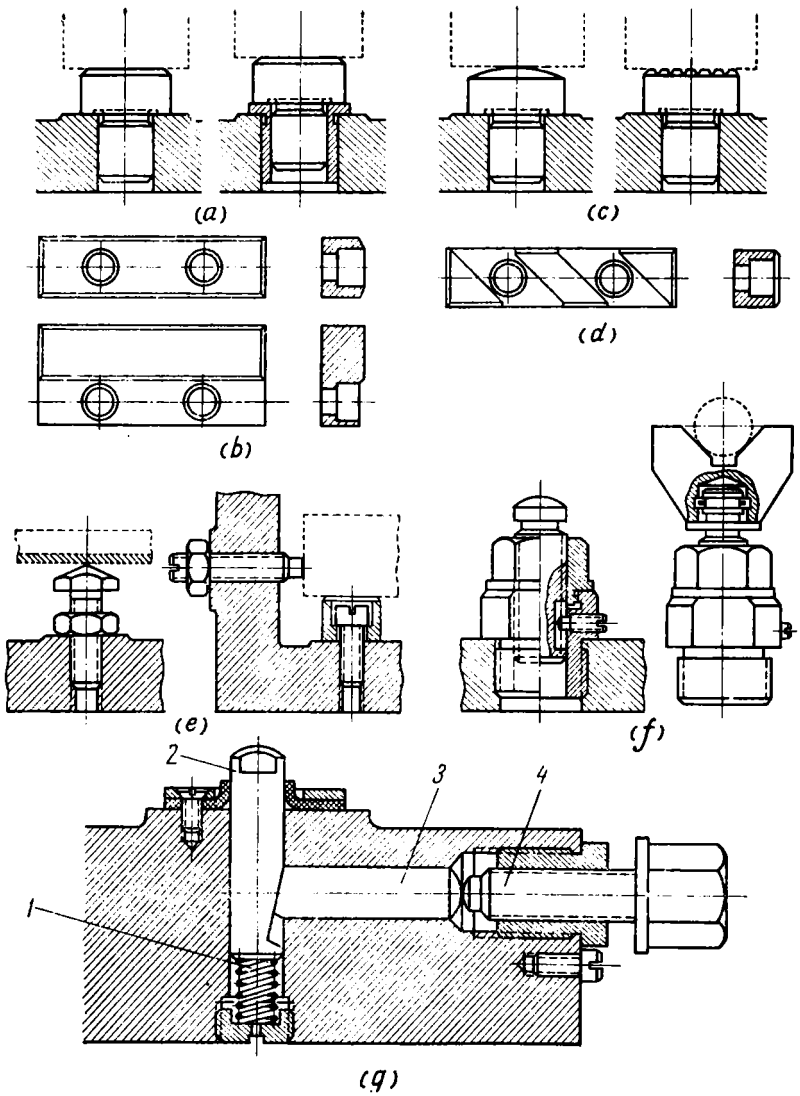


Fig. 167. Rest buttons and pads

(*a*) flat-headed rest buttons; (*b*) plain pads; (*c*) buttons with spherical or knurled heads; (*d*) pads with bevelled slots; (*e*) adjustable rest; (*f*) auxiliary rest; (*g*) self-adjusting rest with clamping screw; *1*—spring; *2*—plunger; *3*—slide block; *4*—bolt

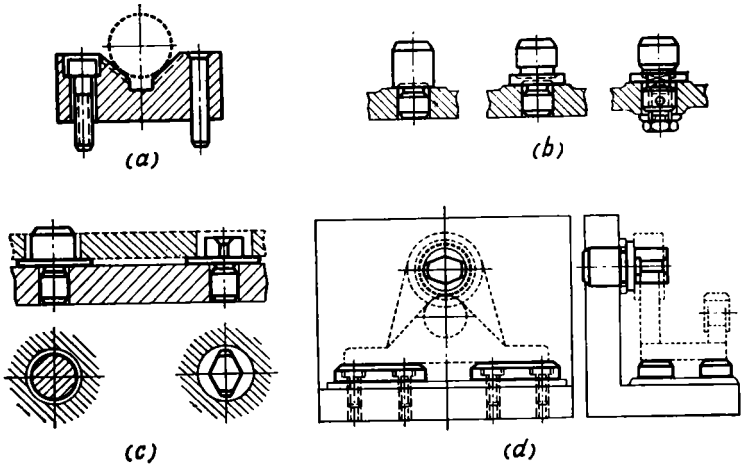


Fig. 168. Locating elements for centering
(*a*) according to cylindrical surface; (*b*), (*c*) according to cylindrical holes; cording to flat surface and hole

The cut in the pin compensates for the errors in the centre-to-centre distance between the locating holes and the locating pins or between the locating surface and the hole due to resulting clearances.

Orienting and self-centering fixtures. Some of the workpieces when mounted in the jig or fixture are to be oriented to their planes of symmetry. The devices used in such cases are provided not only with centering but also with clamping means. Figure 169*a* shows an orienting mechanism with fixed V-block *1* and movable V-block *2*. In machining castings and forgings of different length, fixed V-block *9* is made adjustable (Fig. 169*b*) to finally adjust it to the size of the batch of workpieces.

Figure 169*c* shows an orienting device with self-centering levers. The workpiece is rested against levers *5* and oriented longitudinally by moving plunger *4*. When the plunger is withdrawn, the levers set on axes *6* and retracted by spring *7* release the workpiece.

Clamping elements. The purpose of clamping elements is to provide for an invariably stable position of the workpiece

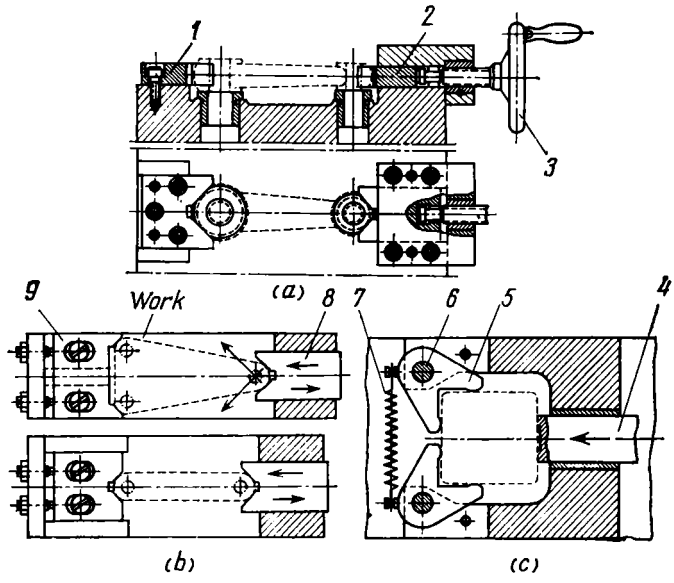


Fig. 169. Orienting and self-centering fixtures
(*a*) with fixed and movable V-blocks; (*b*) with adjustable V-block; (*c*) with self-centering levers; *1*—fixed V-block; *2*—movable V-block; *3*—handwheel with screw; *4*, *8*—plungers; *5*—self-adjusting levers; *6*—axis; *7*—spring; *9*—adjustable V-block

as located in the jig or fixture and acted by forces due to different machining operations. The clamping elements must not deform the workpiece or mar its surface.

The elements employing the action of wedges, screws, eccentrics, levers, hinges, etc. are referred to as clamps.

Wedge-operated clamps (Fig. 170) are most frequently used. They allow the workpiece to be clamped directly or by means of straps or levers. To be self-locking the wedge should have an angle of not more than 6°.

Cam-operated clamps are a kind of a wedge (curvilinear wedges). They can be made as sectors, discs, or cylinders whose working surfaces can be either a circle, or a logarithmic or else Archimedes spiral. The circular eccentrics (Fig. 171) are most popular.

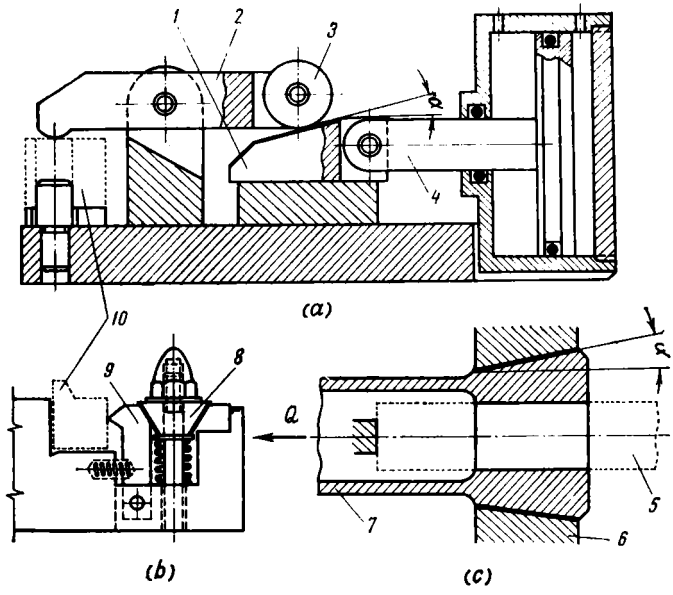


Fig. 170. Wedge-operated clamps

(*a*) mechanism with flat single-bevel wedge; (*b*) mechanism with double-bevel wedge; (*c*) collet mechanism; *1*—wedge; *2*—lever; *3*—roller; *4*—pneumatic drive rod; *5*—blank; *6*—rest; *7*—collet; *8*—double-bevel lever; *9*—lever with force-away spring; *10*—clamped work; α—wedge angle; Q—force

Screw mechanisms clamp the work directly or by means of a strap. Direct clamping is done by a screw with a stationary nut (Fig. 172,*a*,*b*) or by a nut on a stationary or movable pin (Fig. 172,*c*,*d*).

Lever-and-hinge elements of the clamps are used as the drive and reinforcement members. They can be either of a single-lever or double-lever design. The simplest and most common type of lever-and-hinge elements is a strap (Fig. 170,*a* and *b*; 171,*b* and *c*; 172*c*).

Spring clamps are used when a moderate clamping force is required, this being provided due to the compression by a spring. For producing great constant force, a combination is used wherein springs act in conjunction with pneumatic, hydraulic or electromagnetic drives. Figure 173 shows a

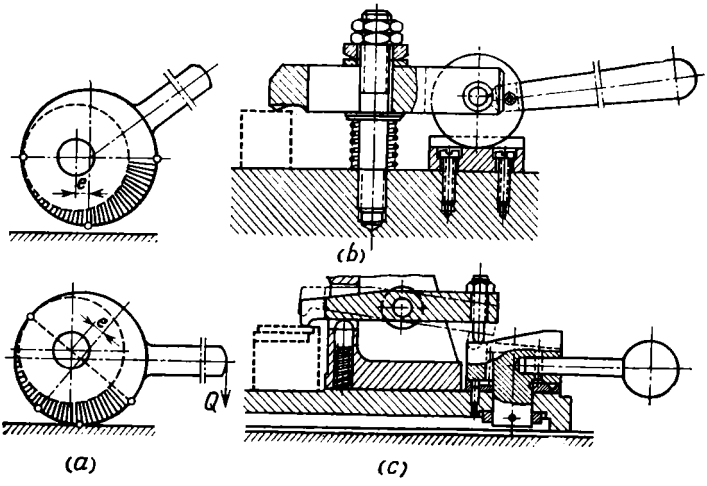


Fig. 171. Cam-operated clamps
(*a*) design and operation of cam (*e*—eccentricity; *Q*—force); (*b*) eccentric with spiral cam; (*c*) eccentric with cylindrical screw cam

spring clamp used in machining a workpiece on a bench drilling machine (*a*) and a spring clamp (*b*) built in a flap cover of a jig.

Tool guiding elements. When machining the workpieces on drilling and boring machines the tools are guided by stationary and rotary jig bushings. Jig bushings can be press-fit, renewable, slip renewable, and special-purpose (Fig. 174).

Press-fit bushings can be made with or without heads.

Renewable bushings, similar to press-fit ones, are used when machining a hole by means of a single tool. These bushings are left in place until worn. To mount the renewable bushings, the jig body is provided with a liner bushing where the renewable bushings are secured by a screw.

Slip renewable bushings are used when machining holes consecutively by means of several tools of different diameters (a drill, counterbore, reamer). To guide each tool, a special bushing is required, therefore a through hole is made for a head of a fastening screw allowing a rapid replacement

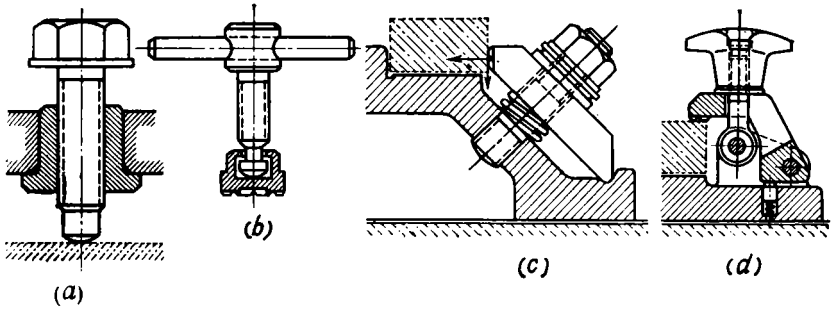


Fig. 172. Screw clamps

(*a*) screw with stationary nut; (*b*) screw with lever and self-adjusting pivot; (*c*) nut on stationary pin; (*d*) nut on movable pin

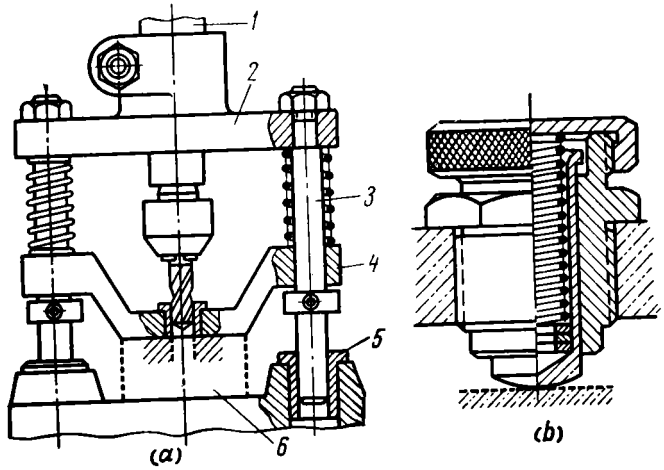


Fig. 173. Spring clamps

(*a*) clamp for drilling machine; (*b*) clamp built in flap cover of jig; *1*—machine spindle; *2*—cross bar; *3*—guide post; *4*—clamping strap; *5*—guide bushing; *6*—work

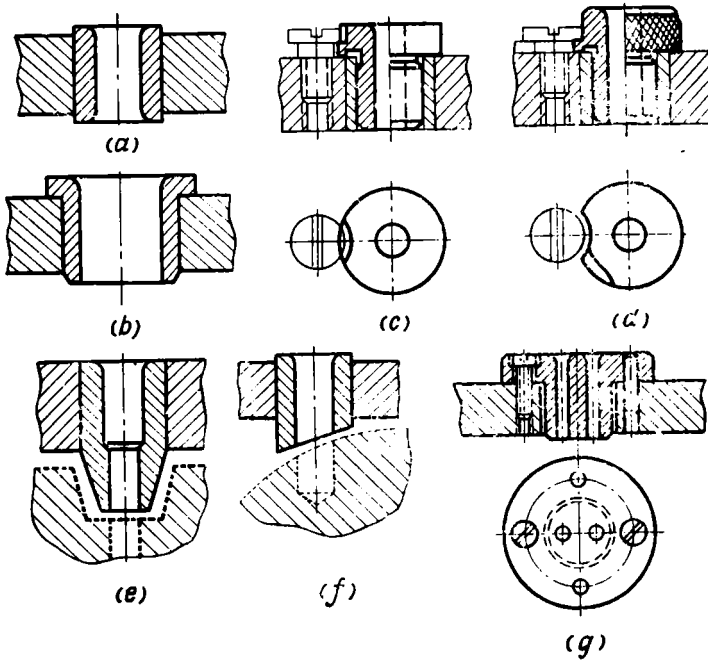


Fig. 174. Jig (guide) bushings
(*a*) press-fit bushing without head; (*b*) press-fit bushing with head; (c) renewable bushing with flat; (*d*) slip renewable bushing with flat and recess for screw head; (*e*), (*f*), (*g*) special bushings

of a bushing. The head is knurled for convenient turning of the bushing.

Jig bushings of special design are used when drilling holes in inclined surfaces, in depressions of parts, as well as when drilling two or more closely spaced holes, etc.

The boring bars are guided in the drill jigs by stationary and rotary bushings. The rotary bushings are mounted in bronze, ball or needle bearings.

Power devices. For more reliable clamping of workpiece use is made of power devices; they can be of pneumatic, hydraulic or magnetic action.

Pneumatic devices are driven by the compressed air under the pressure of 600 kilopascals.

Hydraulic devices are employed in small-size drives and where great clamping force is important. The working pressure of liquid (oil) in the hydraulic devices amounts up to 8 megapascals.

The force exerted by the rod of a pneumatic or hydraulic device is found from multiplying the value of pressure exerted by air or working liquid by the value of the piston working area. For an accurate estimation of the force exerted by the rod it is necessary to account for the loss due to friction between the piston and the cylinder walls, as well as between the rods and the guide bushings and sealings.

Figure 175 presents the diagrams of pneumatic power drives; Figure 176 shows the diagrams of hydraulic devices.

The pneumatic and hydraulic cylinders used for actuating jigs and fixtures can be of two types: double- and single-action, they can be either of a built-in or attach-to design. The attach-to cylinders impart the force to the actuating mechanism mainly by intermediate means, i.e., tie rods, levers, pushers, etc.

Employment of pneumatic and hydraulic power devices calls for use of the fittings, such as distributing cocks for switching-on, reversing and switching-off the power system; throttles (air- or oil-velocity controls), pressure controls, safety valves, air and oil pipeline fittings: nipples, pipe unions, pipelines, hoses, etc.).

Compressed air is fed to power devices through flexible hoses made from rubberized cloth, oil is fed through copper pipes or thick-walled hoses of rubberized cloth enclosed in flexible metal armour (see Figs. 175 and 176). Inside the jigs and fixtures, air and oil are fed through the ducts bored in the body or other parts of the jigs and fixtures.

All the instruments and fittings servicing the pneumatic systems are to withstand the pressure of up to 1500 kilopascals and those used in the hydraulic systems, up to 10 megapascals. However, there are hydraulic systems rated for the pressure of up to 30 megapascals.

Indexing, locking, and auxiliary elements. The indexing and locking elements include indexing devices, devices for handling the elements of jigs and fixtures, the parts for joining individual components and units of jigs and fixtures, etc.

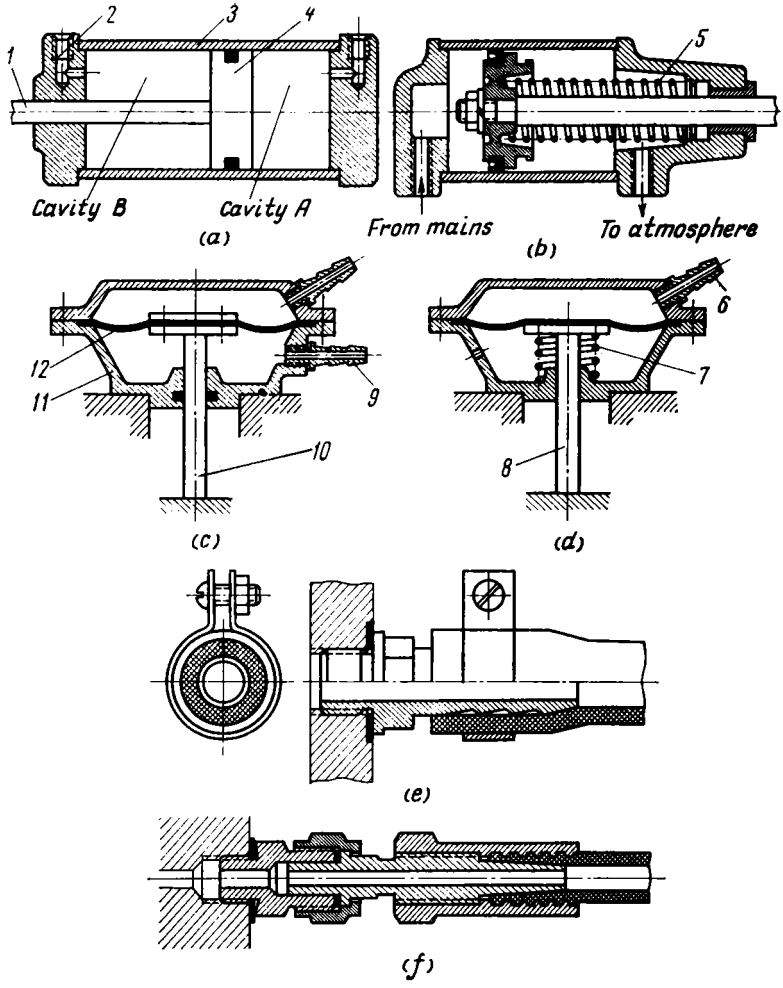


Fig. 175. Pneumatic power drives

(*a*) double-action piston drive; (*b*) single-action piston drive with return spring; (*c*) membrane double-action drive; (*d*) membrane single-action drive; (*e*) connection of hose of rubberized cloth to union; (*f*) same, but through intermediate union; *1*, *8*, *10*—rods; *2*, *6*, *9*—air duct unions; *3*, *11*—bodies; *4*—pistons; *5*, *7*—springs; *12*—membrane

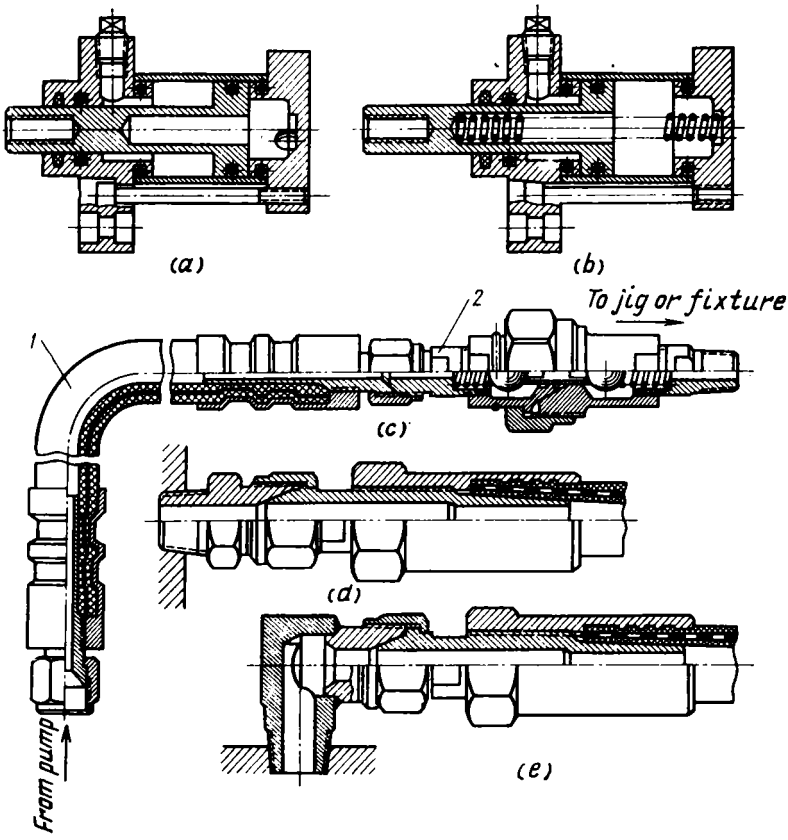


Fig. 176. Hydraulic power devices
(*a*) double-action hydraulic cylinder; (*b*) single-action hydraulic cylinder; (*c*) connection hose with shut-off valve; (*d*), (*e*) terminal connections of flexible hose; *1*—flexible hose; *2*—union

Indexing devices are used for the correct angular or linear positioning of the workpieces. The main elements of the indexing devices are indexing discs and bars (plates), worm gears, toothed racks with gears, and sets of gear wheels. The indexing discs are made as graduated circular plates with slots or bushings spaced over the circumference.

The indexing bars are V-shaped plates whose one edge has definitely spaced slots or bushings. Used as indexing discs can be the bodies of the rotary or movable part of the jigs and fixtures.

Locking devices (Fig. 177) have the form of straight, tapered or prismatic pins whose ends enter the slots or bushings of the indexing disc. The lock is precision-fitted to the guide hole or slot and the indexing disc is introduced owing to the action of springs, rack or cam mechanisms.

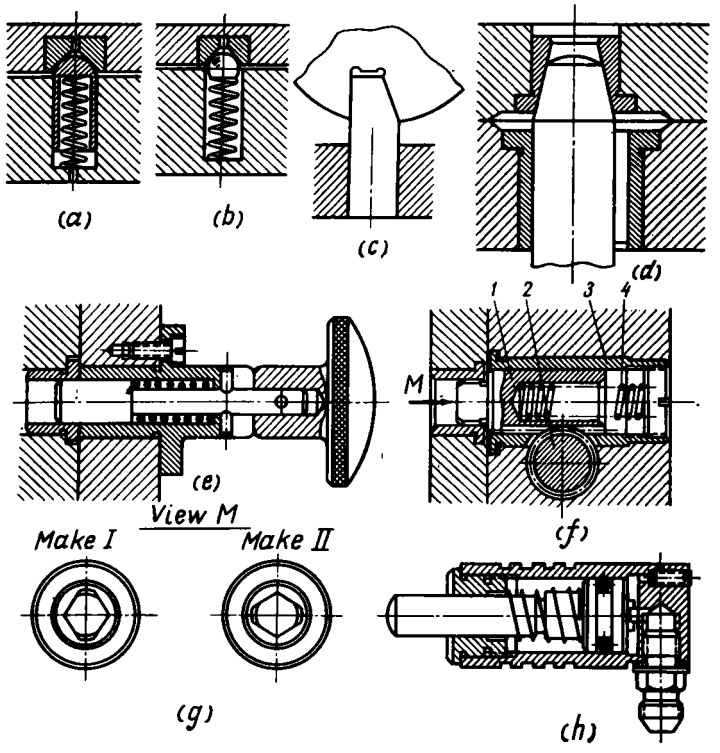


Fig. 177. Locking devices

(*a*) spring lock with spherical pin; (*b*) spring lock with ball; (*c*) wedge type; (*d*) tapered lock; (*e*) cylindrical lock of pull type; (*f*) rack lock of pull type; (*g*) rhomb-shaped pin of lock; (*h*) hydraulically driven lock of pull type; *1*—lock; *2*—gear shaft; *3*—bushing; *4*—spring

The hydraulically operated devices are occasionally provided with the locks actuated by a small-size hydraulic cylinder.

Auxiliary elements include ejectors, catches, locks, handles, and other similar parts used in nearly all the jigs and fixtures.

Bodies, bases or frames. The body, base or frame is the main part of any jig or fixture and mounts the other elements. These elements receive all the forces acting upon the workpiece when it is being fixed and machined. When designing the bodies of jigs and fixtures it is necessary to take into account the convenience they are to offer in mounting and clamping the workpieces, feeding the tools and removing the chips; they are also to allow their accurate mounting and clamping on the machine.

The bodies of jigs and fixtures are cast of iron or welded of steel; they can also be sectional comprising individual bolted members. To make the bodies rigid enough while saving the mass of metal they are provided with reinforcing ribs.

The shape and size of the body depend upon the shape of workpieces as well as upon the arrangement of the locating, clamping, and guiding elements. The body of pneumatic and hydraulic devices can also serve as a reservoir (cylinder, chamber) accommodating compressed air or oil, which also influences its shape and size.

The bodies are the elements most difficult to make, this is why they are standardized. The available standard blanks can be machined to obtain the required body, simple standard bodies can be assembled into more complex ones.

Figure 178 shows the types of standardized bodies.

20.3. Multi-Purpose Sectional Jigs and Fixtures

Manufacturers often resort to multi-purpose sectional jigs and fixtures assembled from standardized, pre-fabricated, interchangeable parts and units. Such fixtures allow a combined application of different jigs and fixtures to perform various operations whereas separate jigs and fixtures are normally intended for one operation on a definite machine tool.

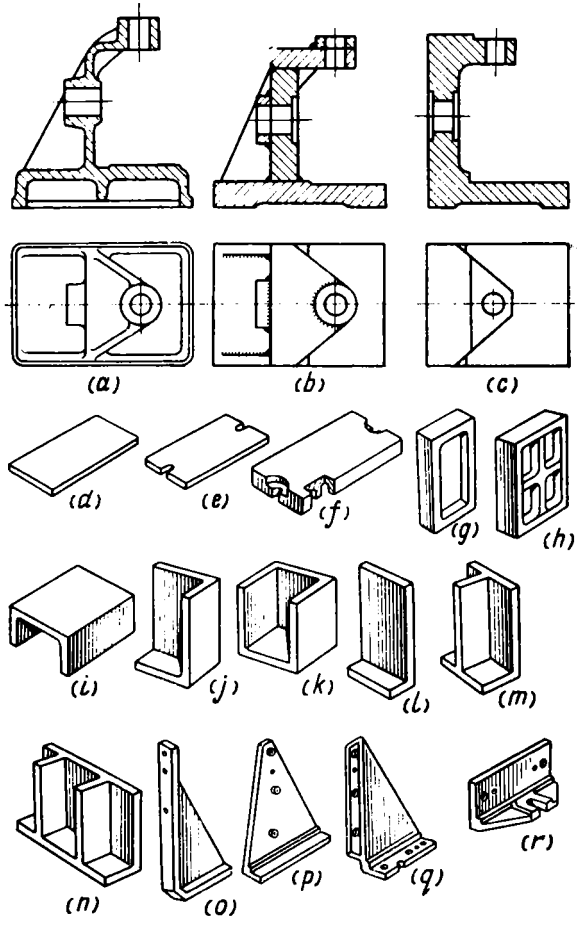


Fig. 178. Bodies of jigs and fixtures

(*a*) cast body; (*b*) welded body; (*c*) body made of standardized blank; (*d*) steel plate; (*e*), (*f*) cast-iron plates; (*g*), (*h*) boxes; (*i*) channel; (*j*) three-plate angle piece; (*k*) open-box four-plate piece; (*l*) angle plate; (*m*), (*n*) ribbed angle plates; (*o*), (*p*), (*q*) ribs; (*r*) lug

The elements of the multi-purpose sectional jigs and fixtures are so designed as to allow the machining of workpieces having different shapes and sizes and the making-up of jigs and fixtures for different machine-tools.

A set of multi-purpose sectional jigs and fixtures comprises base, body, locating, guiding, clamping, fixing, and auxiliary elements, as well as standardized integral units. Figure 179 presents a diagram showing how to assemble the drilling jig using standardized elements and a multi-station grinding device.

The structural compositions of jigs and fixtures employ *base parts* made as square, rectangular, round, and angle plates and rings. The bodies of base parts are provided with T-shaped key slots spaced over a certain pitch. The angle plates are used for assembly of various compositions and for machining the faces of workpieces. The round plates and rings also have T-shaped slots to secure other elements and corresponding holes for their mounting on the faceplates of a lathe or a grinding machine. The base parts are made of castings of chrome-nickel steel, which are machined and, then, carburized and hardened to R_C 58-64. The surface finish of the machined base parts complies with Class 9. The mounting surfaces, key and T-shaped slots are made to Class 2 accuracy, which allows the assembly of compositions to Class 2-3 accuracy.

A group of *body parts* is the most versatile one as to their types, sizes, and purpose. The combination of base and body parts forms the bodies of jigs and fixtures. All the height sizes can be achieved by combining the spacers and supports. The supports are joined by keys, threaded studs, and round nuts to form a firm and rigid unit.

The body parts include rectangular and angular supports, spacers, angle plates, V-blocks, spacing inserts, guiding and locating straps, joining plates.

Most of the linear dimensions in body parts are made to tolerances corresponding to Class 2 accuracy, the tolerances for out-of-parallelism and out-of-perpendicularity of the planes and the precision hole axes complying with Class 1 accuracy. The slots are made to Class 2 accuracy. The working surfaces are carefully ground and brought to Class 9

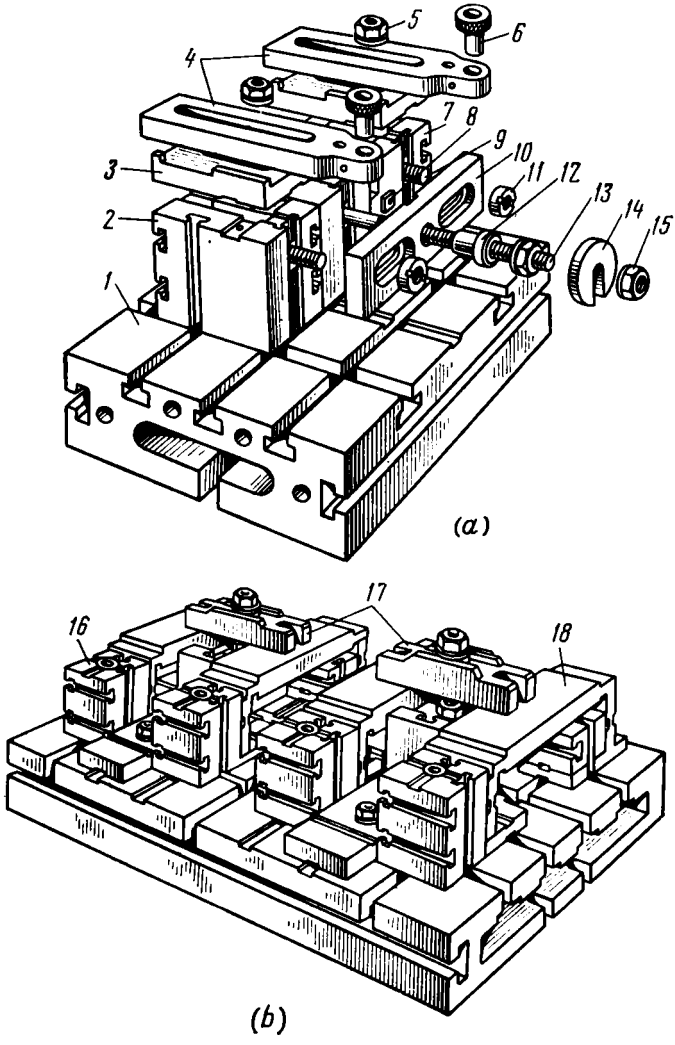


Fig. 179. Multi-purpose sectional jigs and fixtures

(*a*) mounting diagram of jig for drilling two holes; (*b*) multi-station device for grinding; *1*—base plate; *2*, *3*, *7*—guide supports; *4*, *10*—straps; *5*, *11*, *15*—nuts; *6*—bushing; *8*—loose key; *9*, *13*—bolts; *12*—locating pin; *14*—disc; *16*—support units made up of elements; *17*—clamp; *18*—workpieces to be ground

surface finish. These parts are also made of chrome-nickel steel.

Locating elements and guides also vary in sizes and types. They include locating straps, straight and T-shaped keys, locating pins and discs, fixing dowels, simple and adapter tapered bushings. These are made of carbon and chromium steel and hardened with tempering to R_C 48-60. The manufacturing accuracy complies with Class 2 or 1.

Fixing and clamping parts include tacks, studs, bolts, screws, washers, nuts, etc. Such parts are made of different grades of steel, depending upon their purpose: the parts of steel 20 are carburized and hardened to R_C 50-55, those made of rod steel 45 are hardened to R_C 36-42, the parts from wear-resistant alloy steel are heat-treated to hardness R_C 38-42. They are made to Class 3-4 accuracy with the surface finish to Class 7.

Parts of different purposes are those elements of multi-purpose sectional jigs and fixtures which cannot be referred to any of the described groups, as far as their function goes. These include joining and flap straps, rocking straps, threaded straps, lugs, forks, shaped pins, caps, springs, lock rings, handles, counter-balances, junction plates, joining angle plates. All these parts are made from high-quality grades of steel, heat-treated and ground.

A special group is comprised of *one-piece (integral) units* (Fig. 180) which find a wide application for making up multi-purpose jigs and fixtures. They contribute to more efficient and compact design of jigs and fixtures, speed up the assembly process, offer convenience during assembly and maintenance while using the minimum number of body, fixing, and other elements. The units are mounted as self-contained sectional parts of a jig or a fixture.

The one-piece units are also to be interchangeable and wear-resistant, hence the requirements extended to their manufacture, quality of materials, and machining techniques.

20.4. Universal Adjusting Devices

The majority of multi-purpose sectional devices have no clamps. The workpieces machined in them are clamped by power tacks. Many manufacturers use sectional devices

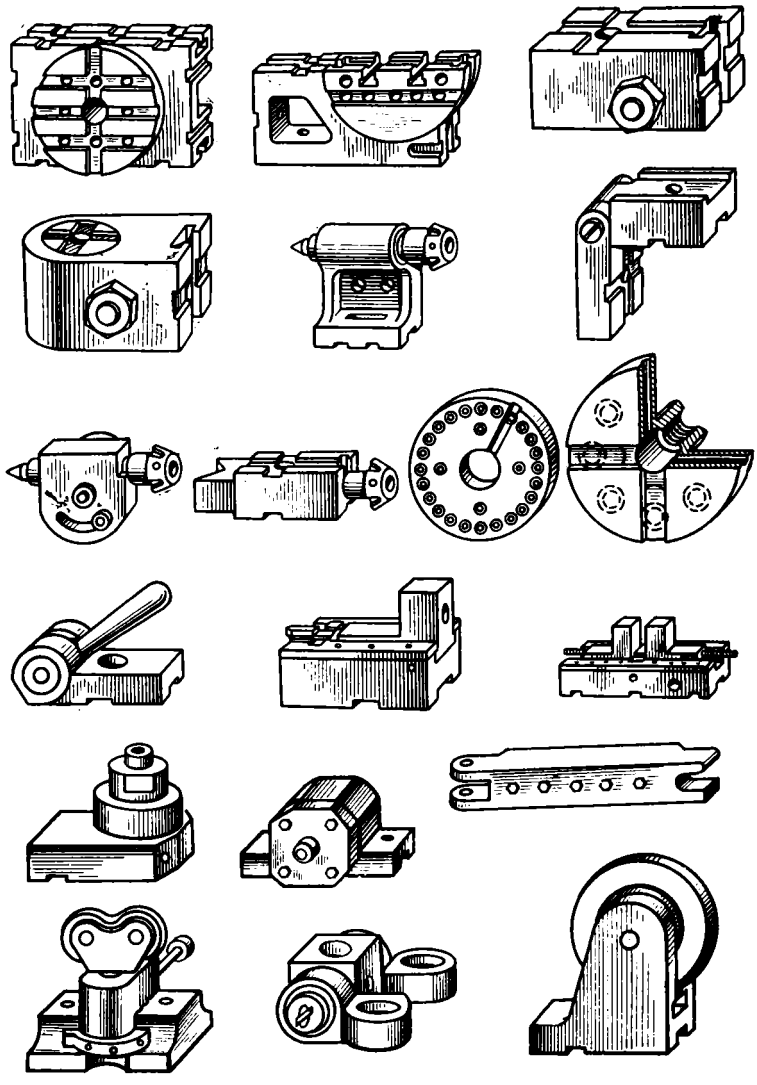


Fig. 180. One-piece (integral) units of multi-purpose sectional jigs and fixtures

made up of standardized units and base elements of repeated application with universal hydraulically-operated clamps.

Such devices are assembled from the ready interchangeable universal units on the base plates, angle plates, and, frequently, directly on machine tables using base elements which can be either standardized or specially made in accordance with the design of a particular part.

Figure 181 shows some standardized universal adjusting devices. A complete set of universal standardized units and base elements consists of 55 typical structures which come in 78 sizes. The base plates and angle plates are provided with T-shaped key slots arranged perpendicular to one another on the upper plane. The slots are intended for mounting body, base and fixing elements, as well as hydraulically-operated clamping tacks.

The adjustable horizontal and vertical tacks are intended for fastening the workpieces. The latter are clamped by the clamping components of the tacks by means of hydraulic cylinders or screws. The tacks themselves are attached to the plates, angle plates or machine table by the clamping bolts. The overhang of the tacks is adjusted by mounting the body, as required, and the stroke of the piston of the changeable hydraulic cylinder. The clamping force exerted by the tacks amounts up to 9-20 kilonewtons depending on the diameter of the changeable cylinder.

No special drawings are to be made up for assembly of the devices; it will be sufficient to have the diagram of the general arrangement of the device indicating all the necessary standardized units and parts. When the device is no longer required, it is disassembled, and the units and parts are handed over to the store where they are kept until wanted for assembling the devices to machine another article. The universal adjusting devices can be readjusted very rapidly and easily to service one workpiece or another, one operation or another. A device of moderate size can be assembled within 30 to 40 minutes.

The hydraulically-operated units which are a part of the arrangement are interconnected by copper tubes or hoses of high pressure with nipples, tee-pieces, and union nuts. All the hydraulic fittings should be rated for the mains

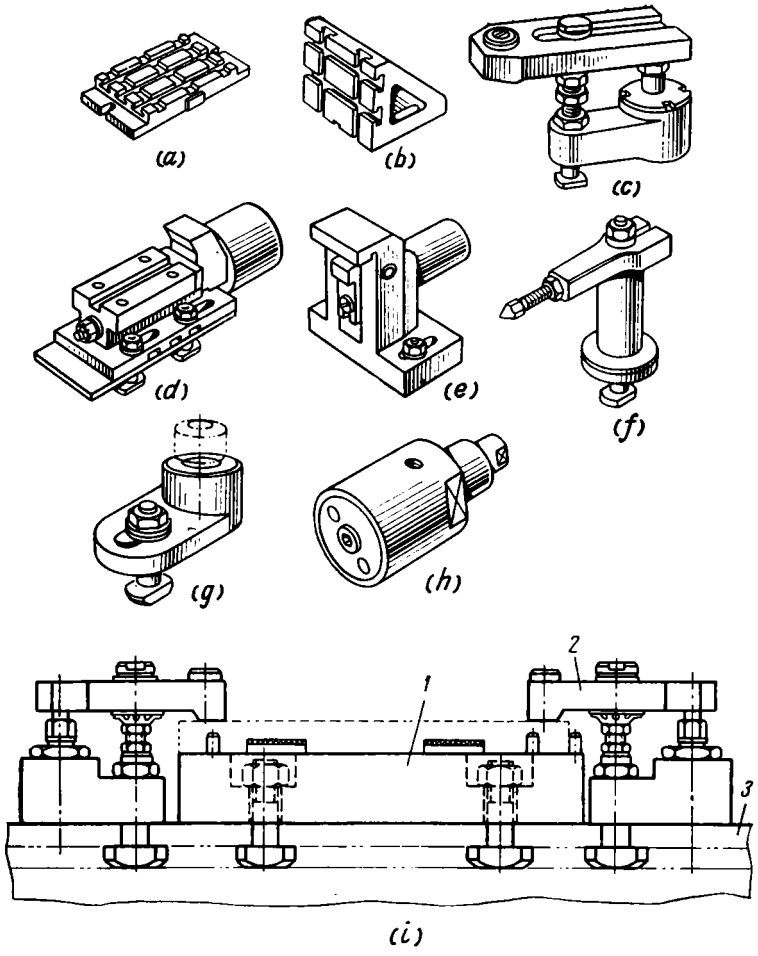


Fig. 181. Standardized units of universal adjusting devices

(*a*) plate; (*b*) angle plate; (c) movable tack; (*d*) *L*-shaped horizontal tack; (*e*) vertical tack; (*f*) adjustable stop; (*g*) base lock; (*h*) hydraulic cylinder; (*i*) device for milling jobs, assembled on machine table; *1*—base unit; *2*—universal clamps; *3*—machine table

pressure of 9-10 megapascals. The hydraulic cylinders can be of one of the four sizes: 25, 35, 40 and 50 millimetres in the bore diameter. The piston stroke of the first two cylinders is 12 millimetres, of the third one 15 millimetres, and of the fourth cylinder 18 millimetres. The cylinder is attached to the power unit by screwing-in the threaded shank of the cylinder. The cylinder piston is joined to the tacks or clamping cams through the threaded hole. Oil is fed to the devices by self-contained pump stations or by plants servicing several machine tools at a time.

Figure 181*i* shows a clamp assembled directly on the milling machine table. The device comprises base unit *1* and two universal clamps *2*. Table *3* of the machine serves as a base plate.

20.5. Devices Using Hydroplastics

For the uniform clamping of several workpieces in a single device use is made of hydraulic chambers filled up with mineral oil or liquid plastics known as *hydroplastics*. The working principle of such a device employs Pascal's law which states that a confined fluid transmits externally applied pressure uniformly in all directions.

Thus, if hydroplastics is placed in a closed chamber of the clamping device and influenced by external force, the hydrostatic pressure will result, which will uniformly act upon all the walls of the chamber. Figure 182*a* shows a diagram of such a device wherein the duct *A* of slide *3* accommodates hydroplastics *5* and three rams *2*. Using screw *4* the slide is moved over guides *6* to clamp workpiece *1*. Threaded plug *7* covers the duct *A* filled up with hydraulic mass.

The pressure from the side of the screw is uniformly transmitted to all the three rams irrespective of the variations in the sizes of workpieces. When unclamping the workpieces the slide and the rams return into the initial position.

Under elevated pressures the liquid fillers easily get into the clearances of the mating movable parts and, therefore, very reliable sealings are required.

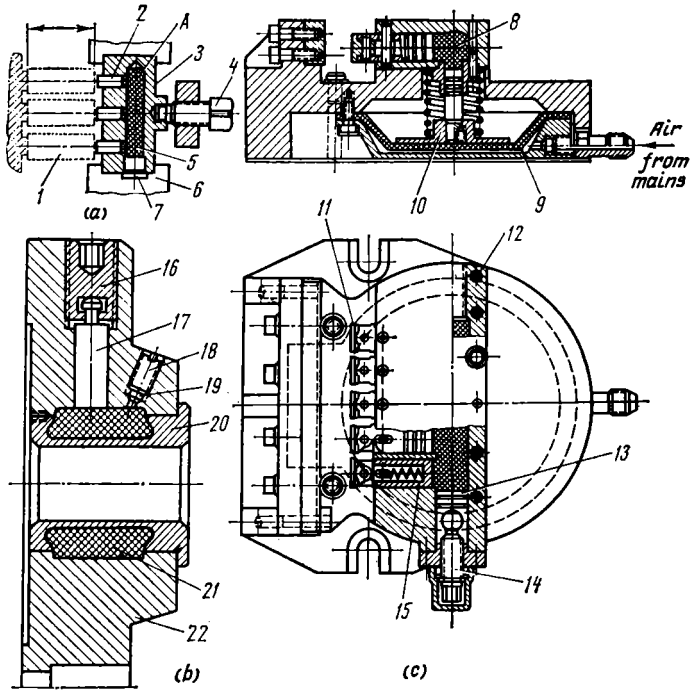


Fig. 182. Clamps employing hydroplastics

(*a*) clamping element; (*b*) self-centering chuck; (*c*) air-operated multi-station vice which transfers clamping force to hydroplastics; *1*—workpieces; *2*, *13*, *15*, *17*—rams; *3*—slide; *4*, *14*, *16*, *18*—screws; *5*, *8*, *21*—hydroplastics; *6*—guides; *7*—threaded plug; *9*—membrane; *10*—pressure ram; *11*—rocking pivot; *12*—pins; *19*—taper plug; *20*—bushing; *22*—body

The best hydroplastics available is that of grades СМ, ДМ, and МАТИ-1-4, which fills the chambers in the best way. These grades are very viscous and will not squeeze into the clearances even under the pressures of up to 30 megapascals and over, their properties do not change with time, they are stable at temperature changes within a certain range and do not corrode the contacting metals. Table 13 shows the per cent composition of hydroplastics constituents and their melting points.

Table 13

Constituents and melting points	Grades of hydroplastics		
	CM	ДМ	МАТИ-1-4
Polyvinyl chloride resin, grade M	20	10	—
Same, grade ПВ	—	—	20
Dibutyl phthalate (plasticizer)	78	88	59.2
Calcium stearate (stabilizer)	2	2	0.8
Vacuum oil	—	—	20
Melting point, °C	140-150	120-130	150-160

To fill up the multi-ram mechanisms the best suitable grade of hydroplastics is grade ДМ which is soft and viscous jelly of light brown colour. ДМ hydroplastics infiltrates in the clearance of 0.01 millimetre under the pressure of over 12.5 megapascals, coagulates at the temperature of 100°C, and is capable of normal operation at the temperatures of —20°C to +40°C.

CM hydroplastics is a brownish mass resembling of crude rubber. It is harder and more viscous than ДМ hydroplastics; it starts infiltrating into the clearances of 0.03, 0.02, and 0.01 millimetre under the pressures of 30, 40, and 45 megapascals. The volume of mass decreases by 0.5 per cent per every 10 megapascals. CM hydroplastics is operative in the temperature range from +5 to +60°C; it is used for filling up the cavities of the centering devices (chucks, mandrels).

Hydroplastics is poured in the device when it is molten. Prior to pouring, the device is heated up to 100-120°C. The mass is usually poured through the hole for the main ram, allowing the air to escape from some other hole (sometimes a special hole can be drilled for the purpose, later it is stopped up). During pouring, the receiving hole is to be in the uppermost position, but pouring should be done by means of a special press, and not by gravity.

Figure 182*b* is a self-centering bore chuck which comprises body *22* attached to the faceplate, check screw *16* with a hexahedral opening for the wrench, ram *17*, thin-walled

centering bushing *20*. Hydroplastics *21* is accommodated between the body and the bushing. Screw *18* and taper plug *19* close the hole through which the air escapes from the cavity of the device when pouring hydroplastics. When screw *16* is rotated, hydroplastics presses against the thin walls of bushing *20* and deforms them uniformly over the entire perimeter. The bushing compresses and, thus, aligns and clamps the chuck-held workpiece to be bored which was previously machined over the external diameter.

Figure 182*c* shows an air-operated multi-station vice wherein the clamping force is provided from the pneumatic power plant and transmitted to the clamping rams through hydroplastics. The compressed air, through membrane *9* and pressure ram *10*, presses against hydroplastics *8* which moves working rams *15* clamping the workpieces (not shown in the figure). When there is no compressed air in the mains, the pressure can be provided by screw *14* acting upon ram *13*. Rocking pivot *11* clamps two workpieces at a time. Thus, the device allows ten workpieces to be clamped simultaneously with equal force. Pins *12* are intended for aligning and locking the components of the device during assembly.

20.6. Electromagnetic and Magnetic Devices

The machine-tool jigs and fixtures having electromagnetic and magnetic force devices can clamp the workpieces without using any power clamps. In such jigs and fixtures the magnetic flux created by the electromagnet or permanent magnet passes through the workpiece which is, thus, a part of the magnetic circuit. This process excites the force which attracts the workpiece to the surface of a jig or a fixture.

The electromagnetic or magnetic jigs and fixtures can be used for clamping the workpieces made of the materials of high magnetic permeability, such as steel or cast iron. These jigs and fixtures are employed on surface grinding and internal grinding machines, i.e., when no considerable shearing force arises during operation performed by cutting tools. The magnetic fastening technique is second to none when rapid and simple clamping of a workpiece to be ground is required. The workpiece, with its locating surface,

is positively pressed against the fixture leaving the rest of the surfaces free for machining. To clamp or unclamp the workpiece is suffice to switch on or off the electric current or to manipulate the handle to move the block with permanent magnets.

The electromagnetic and magnetic jigs and fixtures have gained an especially extensive application at tool-making enterprises engaged in manufacture of dies, moulds, measuring and auxiliary tools and in machining different shaped parts and components. The tool makers use magnetic jigs and fixtures in the form of rectangular, round, and sine plates. The electromagnets are fed with d.c. from the generator or rectifiers.

Permanent magnets are made of special high-carbon steel with admixtures of tungsten, cobalt, and chrome.

As compared to electromagnetic devices, the plates and chucks having permanent magnets are advantageous in the following respects:

they are safe in operation since their employment calls for no power sources;

they consume no electrical power;

they have a long life (from 8 to 10 years without repair).

Chapter 21

Manufacture and Repair of Jigs and Fixtures

21.1. Making and Preparing Blanks

Jigs and fixtures, as a rule, are made as single articles. The principles of lot production are applied only to making standardized elements of re-assembled jigs and fixtures, as well as the parts and units of multi-purpose sectional jigs and fixtures.

The blanks for the components of jigs and fixtures are available in the form of castings, forgings, pieces of ingots, sheets of bar steel, weldings. To relieve the internal stresses causing the warps and cracks in the castings, the cast blanks are subjected to natural or artificial ageing. The

blanks made of steel weldings are heated up to the temperature of 600-650°C and held at this temperature from 1.5 to 3 hours.

The bodies and posts are made from grey iron, grades СЧ12-28 and СЧ15-32 and ordinary-quality steel, grade Ст. 3.

The V-block and flat supports, setups, master forms, cams, locating pins, guide and support bushings which are to be carburized and hardened to R_C 55-60 are made of steel, grade 20.

The tacks, stops, levers, and other parts which can be not very hard are made of steel, grade 45.

Intricately-shaped critical parts are made of alloy and carbon tool steels. Thus, the parts hardened to medium hardness (R_C 45-50) are made of steel, grade 40Х; the bushings transmitting the clamping force through hydroplastics, of steel, grade 30ХГСА, and the base parts of multi-purpose sectional jigs and fixtures, of steel 12ХН3А.

Simple-shaped parts hardened to high hardness (R_C 55-63), for instance, for jig bushings, locating pins of small diameter, collet chucks, master forms and their rolls, are made of carbon tool steels, grades У7А, У8А, У10.

The most popular grade of steel for the purpose under consideration is the grade ХВГ which is indispensable in making intricately-shaped parts or those with thin walls and requiring high hardness.

21.2. Machining Bodies and Plates

The bodies of jigs and fixtures are usually used as boxes, plates or bases with the posts of different shapes and sizes. The bodies of small- and medium-size jigs and fixtures are usually made of standard blanks whose additional machining results in quick and easy making of a required body.

The cast bodies are made according to the following manufacturing scheme: casting, chopping, annealing, removal of cast crust, ageing.

The manufacturing process of making a welded body is different: severing blanks for a body, machining for welding, assembly for welding, welding, annealing.

Some of the operations are common for the two types of bodies: machining the bases and fastening areas of the body, rough machining of the body fastening areas, finish machining of bases, finish machining of locating-and-supporting elements of the body, finish machining of precision and accurately spaced holes of the body.

To make a welded body, the blanks are severed by power saws or oxy-acetylene cutters. Then the blank edges to be welded are machined on shapers or millers. To facilitate the subsequent machining and the mounting of a jig or a fixture on a machine tool, the body base is bored or milled so as to make a depression serving as a support plane. The parts so prepared are marked by the fitter before welding, then they are positioned as required and the welder tacks them by arc spot welding in several places. After the fitter makes sure that the body parts are arranged correctly, the welder makes final welds.

In making the parts of jigs and fixtures, electric welding is preferred, since gas welding results in excessive partial heating and warping of parts.

Machining of bodies is begun with treating datum surfaces. The starting datum surface is normally the support surface of the body. If the latter is round, it should be machined on a turning lathe, a facing lathe or a vertical lathe, the rectangular or octahedral pieces being milled on vertical millers. Depending on the shape of the body, the datum surfaces can be in the form of three mutually perpendicular planes, or a plane and a cylindrical surface (external or internal) perpendicular to it. In some cases use is made of only two mutually perpendicular planes or one hole.

If the support plane and the other surfaces being machined are not enough to serve as bases, then some additional surfaces or holes are machined to be used as manufacturing datum surfaces. The latter are then used in the assembly of jigs and fixtures. The datum surfaces are selected so as to machine them with one setup.

After the datum surfaces are machined the fastening slots in the body base are dealt with. Next goes rough machining of the rest of the body elements followed by finish grinding of the datum surfaces. The planes of the body which are to carry the elements of a jig or a fixture are also finish machined to the Class specified in the drawing. This machining can be done in the form of finish lathe-turning, grinding, and, if necessary, by scraping and testing the work on the surface plate.

Drilling, reaming, and threading of holes in the body

is most frequently performed in the process of assembly. The operation sequence of machining the holes is as follows: when the hole is being drilled, it is first centered by a short centering drill to provide the guidance for a longer and larger drill, then a reamer is taken and an accurate size is obtained by reaming without resetting the work. It may happen that the holes should be reamed during the assembly. Then hand reamers are resorted to, which only size the hole but do not change the direction of its axis if it proves wrong. If one tries to correct the direction of the axis by reaming, an oval hole will be obtained.

The majority of jigs and fixtures employ the plates as their basic elements. Therefore, the process involved in machining a base plate for a multi-purpose device can convey a general idea of the methods used for making the plates for different special devices. The feature of the plates for multi-purpose devices is the close tolerances for flatness, parallelism, and perpendicularity of all the edges and slots of the plate.

After rough shaping and milling of the surfaces and slots the plate is handed over to the heat-treatment division for normalizing aimed at precluding excessive deformation due to the subsequent hardening. After the planes and side edges are rough ground the normalized plate is subjected to artificial ageing. The finish grinding of the plate planes is performed by many passes of the wheel in different directions and using coolants. The plates of checking devices are ground in several operations with an interval of 5 to 6 days.

After grinding, the main plane of the plate is lapped on large cast plates. Lapping is usually done on two lapping plates, one for rough lapping, the other for finish lapping.

To check up the perpendicularity of the edges, not only conventional try squares are used but also a special indicating device (Fig. 183*a*). The latter consists of a height gauge stand with small rest beam *1* and indicator *2* with a scale graduated in 0.005 millimetre. The beam rests against the bottom of the plate, the indicator jaw touches upon the bottom, the jaw being imparted with preliminary interference of 0.2-0.3 millimetre.

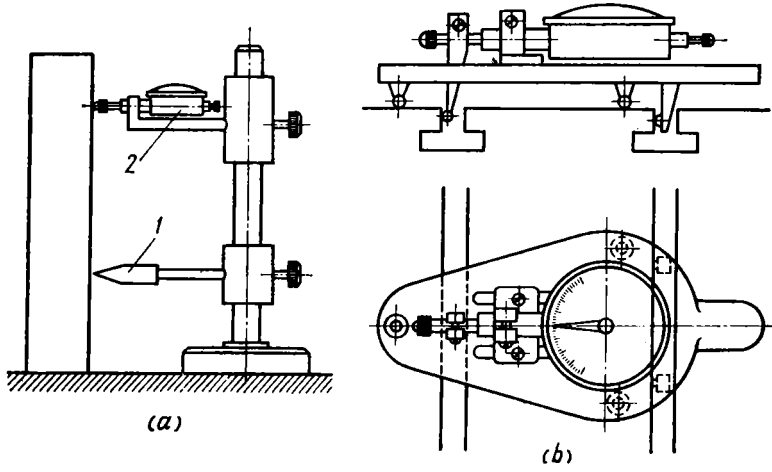


Fig. 183. Methods used for checking up sides and slots in base plates of jigs and fixtures
1—rest beam; *2*—indicator

Measurements are first taken from one edge of the plate and then from the other. The readings of the indicator are taken to judge upon the perpendicularity of the side edge with the basic plane of the plate. If any deviations from perpendicularity are detected, the plate is positioned vertically by the use of aluminium foil spacers. The plate in such a position, the top edge of the plate is being ground. This method of checking and grinding is applied to all the edges of the plate.

After the basic plane and the side edges of the plate are machined, the slots are ground. Grinding is performed by a wheel face of a straight profile with a slight undercut. The indicator is used to check up the position of slots, the design of the indicator is shown in Fig. 183*b*. The body of the indicator is based on the basic plane of the plate according to three points, the other two fixed supports of the indicator are placed along the slot. The movable rod of such a pitch gauge is rigidly joined with the indicator tip secured on the body of the indicator. When check-

ing the slots, the indicator is adjusted using the stack of gauge blocks.

First one side of the slot is ground while checking the pitch by the above indicator, then the other side of the slot is ground while checking its width by the gauge block.

21.3. Accurate Spacing of Holes

Machining of accurately spaced holes is a necessary prerequisite when manufacturing the bodies of jigs and fixtures, jig plates, removable master forms, indexing discs, and other critical parts. To accurately space the holes in the parts is a complicated and responsible job.

With many jigs and fixtures the accurately spaced holes are made on the jig-boring machines. They are versatile machines suitable to perform flat and three-dimensional marking to drill and ream holes with accurate centre-to-centre distances and distances from the datum surfaces, to position the parts and units at the specified distances, and to take different measurements.

When doing small-scope jobs the employment of jig-boring machines is not reasonable. In small tool shops, and when making simple, non-critical jigs and fixtures, simple methods can be used for obtaining accurately spaced holes.

Drilling and reaming operations are very often performed on toolroom vertical milling machines with the devices for reading the longitudinal and cross feeding of the table accurate to 0.02 millimetre. In such cases, higher accuracy of machined holes is accomplished by first drilling the holes of a diameter smaller than the nominal one by 0.5-0.8 millimetre and then boring them by a cutting tool to the required size while accurately spacing the holes.

The spindle of a vertical milling machine can be set in its initial position according to the datum surface *A* to precision-sized ram *1* and gauge block *2* as shown in Fig. 184*a*. To align the spindle axis and the plane *A* the former is to be shifted by the value of $0.5D + e$.

The spindle can be set in the initial position with the aid of a centering indicator according to the available hole or journal as shown in Fig. 184 (*b* and *c*). For this

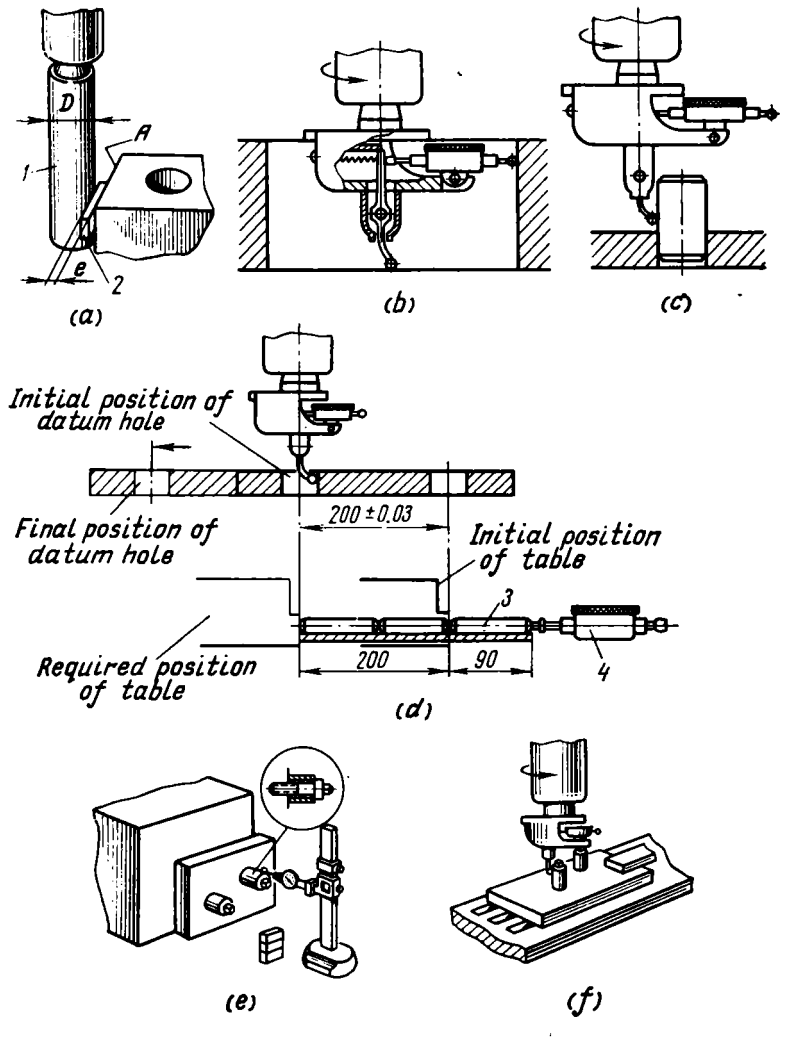


Fig. 184. Methods used for accurate spacing of holes

(*a*) with the aid of sized ram and gauge blocks; (*b*) to available hole; (*c*) with the aid of journal; (*d*) to inside caliper gauge; (*e*), (*f*) to sized bushings (buttons); *1*—ram; *2*—gauge block; *3*—inside caliper gauge; *4*—indicator

purpose the table and the workpiece are moved till the indicator pointer will remain immovable during the rotation. How to proceed from the datum hole to the boring of the next hole or to the measuring of the space between them is described in Fig. 184*d*. The table can be moved using inside caliper gauges *3* and adjusting indicators *4*. For this purpose the inside caliper gauges are placed in a tray and the indicator is set at zero. Then the table is moved according to the set of inside caliper gauges to the size of 200 millimetres, i.e., when the indicator pointer is again at zero.

Another method for boring the holes is that by the use of buttons. First the position of hole centres is marked, the holes are drilled by small-diameter drills and threaded for screws by means of which the precision-ground bushings are secured over each hole. The surface plate in conjunction with the gauge blocks and the indicator serves for correct spacing of bushings (Fig. 184*e*). After the work is mounted on the table of a vertical milling machine the axes of the spindle and the bushing (Fig. 184*f*) are aligned using the centering indicator secured in the machine spindle. Thereafter the bushing is removed and the hole over which it was secured is bored. The first hole bored, the spindle is adjusted according to the next bushing, and the next hole is then bored.

The accurately spaced holes can also be obtained by boring them on a faceplate of a lathe with the use of different devices. A simple type of such a device shown in Fig. 185*a* comprises faceplate *1* and try square *2* bolted to the faceplate. Marked-off workpiece *3* is secured to the faceplate so that its one datum surface tightly contacts against the try square while a stack of gauge blocks *4* equal in size to the value of *C* is placed beneath the other datum surface. Then the first hole of the work is drilled and bored.

During further machining the work is moved resting it against the try square (Fig. 185*b*) while keeping in place the mounted stack of gauge blocks and placing the other one (equal in size to the distance of *B* between the centre holes) beneath the other datum surface. All this done, the second hole is bored. The rest of the holes are machined after resetting the workpieces on the faceplate. The lower

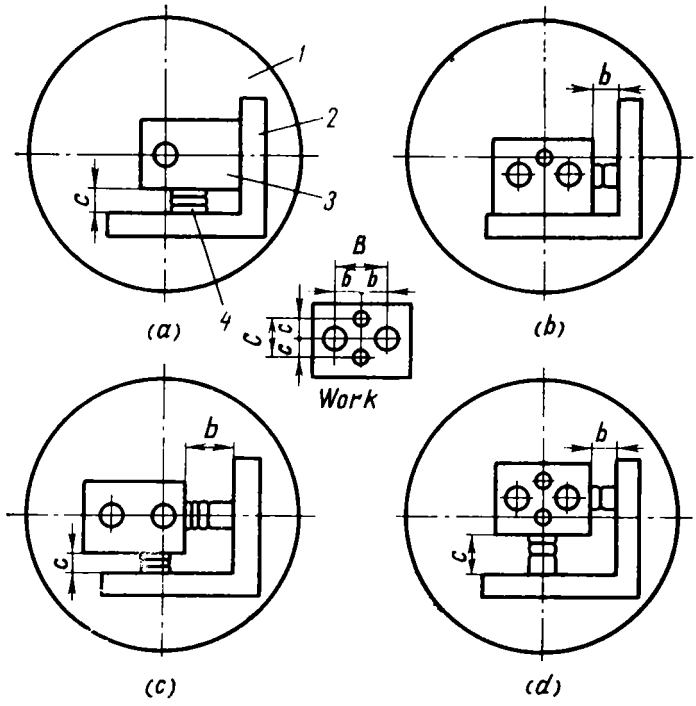


Fig. 185. Accurate spacing of holes when boring workpiece on lathe faceplate

1—faceplate; *2*—try square; *3*—workpiece; *4*—gauge blocks

stack of gauge blocks is removed and placed on the plane of the try square, while the stack of gauge blocks equal in size to that shown in the drawing (Fig. 185*c*) is placed beneath the other datum surface.

The last hole is bored when the stack of gauge blocks equal in size to the value of *C* is placed under the work (Fig. 185*d*), the previously-mounted stack of gauge blocks being in place.

The gauge blocks are used only for mounting the workpiece. When the latter is secured in place on the faceplate they are removed and the boring operation is started. This technique allows spacing of holes to be obtained accurate to 0.01 millimetre.

21.4. Assembly of Jigs and Fixtures

The assembly of jigs and fixtures is a combination of operations and operational elements of bench fitting and machining involving also complicated and accurate measurements. The parts requiring no bench fitting (screws, tacks, stops, nuts, etc.) are handed over to the assembly as ready pieces. The parts calling for bench fitting are first machined and heat-treated.

The task of the assembly man is to accurately mount the parts and units with respect to the datum part and to join them in the proper consecutive order.

When dealing with complicated jigs and fixtures it is expedient to divide the assembly operations into those concerning individual units and general assembly operations.

Though the jigs and fixtures come in a great variety of designs it is quite possible to suggest a certain order for performing assembly jobs. This may be as follows:

(1) See whether the parts and units delivered for assembly are in a complete set and in good condition.

(2) Perform bench fitting operations.

(3) Check up and assemble the support plane and datum surfaces of the body.

(4) Fit the surfaces of the body to the supports.

(5) Mount, fix, and finish the supports, locating and guiding parts and units.

(6) Mount, fix, and finish the movable locating parts and units.

(7) Drill, thread, and assemble the clamping units and parts of jigs and fixtures while checking whether the workpieces can be clamped correctly and reliably.

(8) Stamp the jigs and fixtures according to the drawing.

(9) Mount and fit the key slide blocks for mounting the jig or fixture according to the machine slots.

(10) Finally check up the maintenance sizes and see whether the jig or fixture complies with the specifications.

(11) Balance the revolving jigs and fixtures.

(12) Test the ready jig or fixture in operation and submit it to the technical inspection department.

Prior to assembly, it is necessary to carefully check up whether the sizes and geometrical forms of delivered

pieces comply with those indicated in the drawing. The sizes are checked up by micrometers, vernier calipers, depth gauges, inside caliper micrometers, gauge blocks, height gauges, indicators. The geometrical form of rectangular pieces is checked up by straight edges, try squares, and the shaped pieces are tested, when necessary, by protractors and templets.

To spare time and to improve the assembly quality, it is necessary to machine the workpieces of the article to the accuracy specified by the drawing, observing the following requirements:

(1) the datum surfaces should be dead perpendicular with or parallel to one another;

(2) the planes locking the workpieces should be rectilinear or strictly correspond to the outline of the part;

(3) the holes for jig bushings should be dead perpendicular with the plane where they are bored;

(4) the stops positioning the workpiece in the jig or fixture should be on a common horizontal line;

(5) the screw, wedge-type, lever, and cam clamps are expected to reliably hold the workpiece in the position necessary to perform operations upon it;

(6) the internal and external diameters of jig bushings should be strictly concentric.

The multi-purpose and special jigs and fixtures are assembled and fitted in place. When very accurate conjugations are required, use is made of filing, lapping, and scraping.

Prior to assembly, the workpieces are cleaned and washed with kerosene or gasoline. The non-machined surfaces of castings and forgings are cleaned off rust, scale, and marks left by moulding materials, which is done by steel hand or power brushes. The internal surfaces of non-machined castings and forgings are primed and coated with oil paint. The above requirements are compulsory since unpainted pieces dropping scale and sand mar the surface and marking-off plates.

The fitting jobs include filing the shaped surfaces and edges; chopping oil grooves; removing excessive stock in the places inaccessible for machining; trimming, grinding, and polishing the surfaces by power tools so that they

comply with the drawing specifications. Where required the holes are drilled, reamed, and threaded.

The datum and guide surfaces are scraped. When scraping small areas, a stock of metal thick up to 0.05 millimetre is removed, for large areas this figure can be 0.1 millimetre.

The parts which are to be joined air-tight with movable fits without clearances should be lap finished. The allowances for lapping the planes are, as a rule, 0.03-0.05 millimetre, and 0.01-0.02 millimetre for lapping the ground holes. In most cases lapping is applied to the guide surfaces and to the parts of pneumatic and hydraulic jigs and fixtures. Lapping is done either on machines or manually using the devices for guiding the pair of workpieces. For manual lapping use is made of power electric or pneumatic tools.

Some hardened parts of jigs and fixtures (master forms, setups, rests, etc.) are ground manually with the aid of hand power tools (using a set of abrasive tools for them). Manual grinding is done by means of whetstones of the required cross section and size made of both natural and synthetic abrasive materials. For manual grinding it is better to use harder abrasive whetstones than those employed in power grinding. The whetstones, which lose their shape and abrasive properties, are reconditioned by dressing them on cast-iron plates charged with abrasive powders.

All the sharp corners of the machined parts are rounded off with a corner radius of 0.5-1.0 millimetre or chamfered making chamfers of 0.5-1.0 millimetre in width at an angle of 45°.

When assembling a jig or a fixture, the work always starts with mounting the datum part and fitting its joining places to the other parts. The datum part is so mounted and secured that the datum surfaces are oriented with respect to the measuring datum. This operation is referred to as provision of the initial position in which the datum part is to be stable and stationary. If the datum part cannot be made stationary by its own mass, it should be attached to the surface plate or the canting box by tacks or screw clamps.

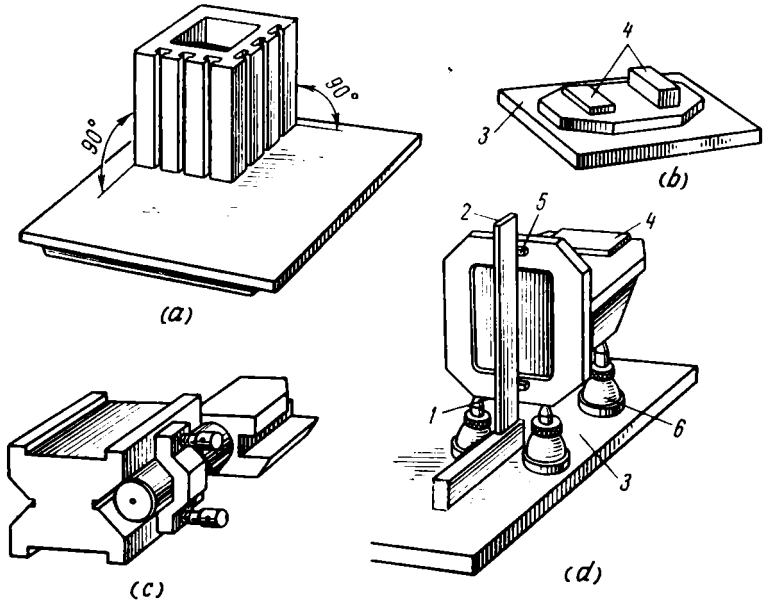


Fig. 186. Mounting of datum parts
(*a*) surface plate and canting box; (*b*) mounting of parts directly on plate (*c*) mounting on canting V-block; (*d*) mounting on jacks; *1*—support surface; *2*—try square; *3*—surface plate; *4*—datum surface; *5*—gauge block; *6*—jack

To attach the datum part to the canting box (Fig. 186*a*) is especially suitable since canting the box allows the position of the part to be verified at three different projections. When being canted the box and the part are so turned as to place the datum or mountable part with its surface to be measured or machined parallel to the surface of the plate.

A usual practice used in mounting the datum part is to set the body of the device on the surface plate with its base (Fig. 186*b*). This technique allows fitting and assembling operations to be performed upon the planes parallel to the body base.

If the parts being mounted are set with respect to the axis line of the precision-machined cylindrical component of the basic part, the latter is secured against the canting V-block (Fig. 186*c*).

For convenient mounting of the parts on the surfaces perpendicular with the support plane of the body, the datum part is placed on the jacks or wedges positioned at three points (Fig. 186*d*). The datum part is mounted on two similar gauge blocks to the try square with a wing. The positioning is considered accomplished if the two blocks are held in place by the beam of the try square made to contact the support surface of the datum part. This method offers more accuracy than that wherein the part is set to the try square and tested for light clearance.

When assembling a device, it is necessary to adjust and verify the mutual position of the parts and units. The pieces in the position found to be suitable are locked by locating pins. For this purpose the assembled and bolted parts are drilled in by the assembly man and the holes are sized with reamers for wringing or tight fit, Class 2 accuracy. These holes admit cylindrical pins which are forced in under the press or driven in by tapping against with a copper hammer.

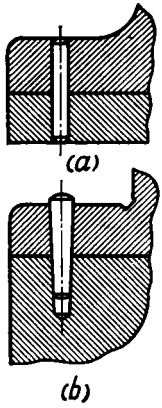


Fig. 187. Locating pins
(*a*) cylindrical; (*b*) taper

To lock two pieces it is necessary to set at least two pins spacing them as far apart as possible. The position of the locating pins is so selected as to make through holes for them (Fig. 187), otherwise the removal of the pins during disassembly will be too difficult. If through holes are not available, taper pins are driven, the holes for them being machined by a taper reamer.

For a higher accuracy it is possible to machine simultaneously one or several parts together with the body of the device after preliminary assembly. For instance, to provide for aligned holes in several parts assembled on a common body, they are bored with one setup; for better alignment the locating surfaces of several supports are also ground together after their final mounting on the body.

21.5. Making and Mounting Jig Bushings

Similar to many other parts of jigs and fixtures, the jig bushings are delivered for assembly as ready machined and heat-treated pieces.

The bushings are made on the lathes using steel, grade Y10A and hardened to hardness R_C 60-64. Large-diameter bushings are made of steel 20 with their subsequent carburizing and hardening to the same hardness.

A critical operation following the lathe turning and heat treatment is that of external and internal grinding of bushings. The shouldered bushings are ground over the external and internal diameters on the universal cylindrical grinding machines in a chuck with a single setup, the accuracy being to Class 2. For a high surface finish the holes in the bushings are lapped using the expansible copper laps and pastes.

To provide for a reliable fit of press-fit bushings, their external diameter is ground leaving 0.01-0.02 millimetre allowance exceeding the diameter of the hole in the jig plate. For better press-fitting, the external surfaces of the bushings are coated with water solution of blue vitriol. By tapping against the bushing with a hammer it is driven into the hole to the depth of 3-5 millimetres, the rest being done by a lever of hydraulic press until the bushing is as deep in the hole as required.

After each bushing is press-fitted, it is checked to see whether the axis of its hole is perpendicular to the plate plane. This is done by a gauge introduced in the bushing hole, mould square, and two gauge blocks employing the technique described in Fig. 186*d*. The centre-to-centre distance is verified by round gauges and gauge blocks placed between them. The wrongly press-fitted bushings should be removed, the cause of inaccuracy detected and remedied. Then either the same or other bushings are press-fitted again.

21.6. Making Jig Plates with the Use of Quick-Setting Plastics

When making jig plates, the precision boring of several holes in the plate on a jig boring machine can be dispensed

with and substituted for by lining the jig bushings with plastics.

Such a plate is made as follows (Fig. 188). The surface of a plain metal plate *1* is pressed against, with a screw clamp, by marking-off square *2* whose internal planes are employed as the axes of coordinates governing the position of horizontal and vertical axes for placing jig bushings *3*.

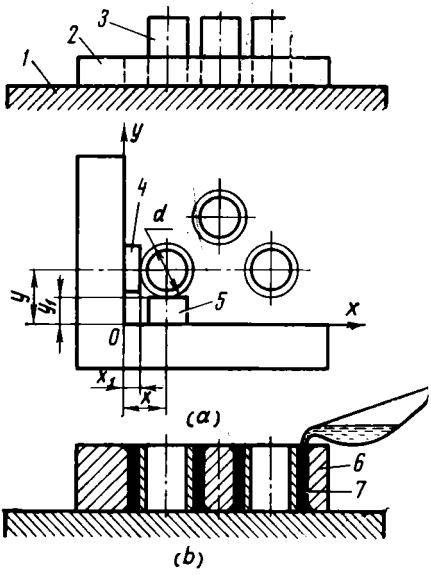


Fig. 188. Jig plate with bushings secured by the use of plastics

(*a*) mounting of jig bushings to gauge blocks and try square; (*b*) lining the bushings with quick-setting plastics; *1*—surface plate; *2*—marking-off square; *3*—bushing; *4*, *5*—gauge blocks; *6*—jig plate; *7*—plastics

To set a bushing in the required position, its external diameter d is accurately measured and, over the abscissa x, the size of $x_1 = x - \frac{d}{2}$ is combined of gauge blocks *4*.

To place the bushing over the ordinate y the size of $y_1 = y - \frac{d}{2}$ is combined of gauge blocks *5*.

The correct position of the bushing will be achieved by firmly pressing the bushing and the gauge blocks against the beams of the square. To lock the bushing in place, its face is coated with weak epoxy (or other) glue and pressed against the plate. The rest of jig bushings are mounted and fastened in the similar way.

After the bushings are mounted on the surface plate, jig plate *6* made of structural steel is put on them. The plate is to have holes for bushings drilled with a clearance

of 4-6 millimetres over the diameter of the bushings and counterbored on both sides.

Before the jig plate is put onto the bushings, the surface plate is coated with the parting compound, and the surface of the bushings and the hole walls of the jig plate are carefully degreased with gasoline or acetone.

When mounting the jig plate, its sides are thoroughly verified to the marking-off square, then pressed against the surface plate by screw clamps, and, finally, plastics 7 is poured between the walls of the plate holes and the bushings.

After the plastics have set, the centre-to-centre distances of the jig bushings are verified by the plug gauges and gauge blocks. By tapping against the plate, the jig plate and bushings are separated from the surface plate. The traces left by glue are washed off the plate and the faces of the bushings using suitable solvent, excessive plastics being removed from the jig plate by bench tools.

21.7. Cementing the Elements of Jigs and Fixtures Together

The parts made of metals, plastics, rubber, and other materials are joined by means of synthetic cements. There exist cold-setting and hot-setting cements. Rubber cements are classified into those requiring hot vulcanization and those which are vulcanized when cold (owing to introduced additives).

Some synthetic-resin-based cements allow joining plastics to one another, plastics to metals, metals to one another, and rubber to plastics or metals. These cements prove unsuitable for joining rubber to rubber, this being done by natural-rubber-based cements.

A wide application for making cements has been gained by phenol-formaldehyde resin. It serves as a base for several grades of Soviet-made cements, such as БФ-2, БФ-4, БФ-6. Some of them are universal cements suitable for joining a great variety of materials. They are to be heated up to 120°C and over to make them finally set.

The epoxy-resin-based cements ensure firm joints (for instance, the shearing strength is 35-70 megapascals), do not require strong pressing of pieces to be joined, do not

cause corrosion, and can set both when cold and hot. No special requirements are extended to the accuracy and finish of the surfaces to be joined. However, the most reliable joints result from applying a coat of cement from 0.05 to 0.10 millimetre for which purpose the surfaces are to be carefully degreased.

The epoxy cements can resist well the action of coolants (sulphophresol of emulsions, mineral and vegetable oils). They do not swell or weaken due to moisture.

A disadvantage of epoxy cemented joints is their poor heat resistance: their strength drops sharply when heated up to 90°C and over. Long seasoning of cemented pieces contributes to the strength of the joint, while heating speeds up the setting process. The cemented joints can withstand well dynamic and variable loads, but are liable to creep when influenced for a long time by great static loads (for instance, the force exerted by bolt fastenings).

The cemented joints can be used for assembly of parts contacting each other over the cylindrical, tapered, flat, and other surfaces. They can often substitute for screw, pin, key joints, and those made by press-fitting. Application of cemented joints allows simplification of the design of the tooling equipment units, reduction of fasteners involved, while making the demands for manufacturing accuracy not so exacting.

Unlike the welded and brazed joints, the cemented units do not deform. At the same time, the cemented joints are easy to disassemble when heated partially or as a whole unit up to 300-350°C.

The cement mass is prepared from epoxy resin, its composition being as follows: 100 weight parts of resin, 8-9 weight parts of hardener (polyethylene polyamine) and 10 weight parts of plasticizer (dibutyl phthalate). The cement should be prepared right before using it, since in 45 minutes after it is made its action weakens.

To make hot-setting cement, malein anhydride heated up to 60°C is introduced into the same amount of epoxy resin (35 weight parts). The cement sets when heated up to 120°C and held at this temperature for 5 hours.

Such a joint will be 1.2-1.5 times as strong as that made with cold-setting cement.

The hot-setting cement can be kept in a closed container for a long time.

21.8. Graduation of Scales

Many jigs and fixtures are provided with different linear and circular scales. Accurate graduation is done by means of special indexing machines which, however, are not available in common tool shops where graduation is done on jig-boring machines fitted out with accurate movement counters.

To make a linear scale, the blank is secured on the machine table and verified according to one of the coordinate axes of the slide travel. To make a circular scale, the workpiece is secured in the chuck of a swivel table or on the swivel table using tacks. The workpiece axis is aligned with the axis of the table swivel.

The graduation lines are made by a sharp spring prick punch or a tool secured in the machine spindle.

In the latter case the spindle is locked against unnecessary revolutions. The lines can also be made vertically by a bent tool. The tool is moved vertically by lifting and lowering the spindle, the amount of travel being measured by counters mounted on the machine. The tool made of steel has the plan approach angle of 40-60°, the side relief angle of 6°, and the negative rake of 3°. The cutting edges of the tool are dressed with diamond whetstones.

The circular scales on the tapered surface and the linear ones on the sloping surface are made on the tilting table. The table axis is so tilted that the taper generatrix (sloping surface) is horizontal or vertical depending upon the assumed method of graduating.

The jig boring machines (Fig. 189) can be provided with a special device which speeds up the process of making lines on scales. It can be attached to the body of the machine stock with the aid of V-block *1* (the shape of this part is variable depending on the type of machine) or in the locating hole of the spindle with the aid of a shank set in V-block *1*.

Guide *2* can turn about axle *3* and is secured by nut *4* in the required position. The upper guide surface has li-

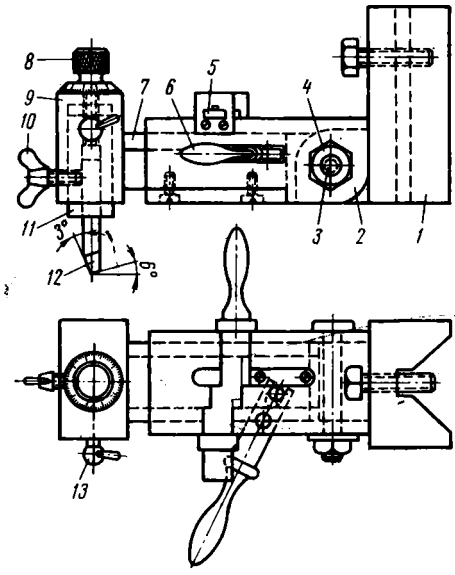


Fig. 189. Device used for graduating scales
1—V-block; *2*—guide; *3*—axle; *4*—nut; *5*—limiter; *6*—handle; *7*—slide; *8*—dial; *9*—head; *10*—wing nut; *11*—tail spindle; *12*—tool; *13*—screw

miter *5*; handle *6* is used to move slide *7* with head *9* on its front part, the head accommodating tail spindle *11* with tool *12*. The tool is secured in the tail spindle by wing nut *10*, the overhang of the tail spindle being adjusted by dial *8* and locked by screw *13*. The steps of the limiter are intended for variations in the length of lines when plotting the fifth and tenth divisions of the scale.

The reading of the pitches off the scale divisions is done with the aid of the machine measuring devices when the table slide and the spindle headstock travel, or the table rotates (in case of plotting circular scales).

21.9. Checking Up of Assembled Jigs and Fixtures

A ready jig or fixture can be checked up best by testing its performance upon the workpieces it is intended to ma-

chine. The test period can reveal all the shortcomings pertaining to its design and manufacture, which should be corrected before the jig or fixture is handed over to the users.

The assembly will be of high quality if the following requirements are met:

1. Do not allow the assembly of parts whose sizes, shape, surface finish, and tolerances deviate from those specified by the drawing.
2. If machining cannot yield the prescribed accuracy, achieve the specified sizes and shape by bench operation and by fitting the pieces to one another.
3. Always check up the mutual position of the elements in the jig or fixture with respect to the three planes of the coordinate system, use checking and measuring tools for the purpose.
4. Observe the following sequence when assembling the units and the jigs and fixtures as a whole: first prepare the body, then check up, mount, and finish each part and unit in assembly. Never mount any part till you make sure that those already assembled are of the prescribed sizes and mounted properly.
5. Avoid mounting the parts and units directly to the holes, use gauges, locating pins, and other aids.
6. The thin-walled bushings press-fitted in the body holes, in the supports or on the shafts should be finished in assembly, since press-fitting may distort their sizes.
7. Check up the prescribed sizes, run-out of movable parts, and departure from true geometrical shape when the jig or fixture is in the working position.
8. Use as many locking pins as necessary for reliable mounting of parts and units to facilitate further assembly and disassembly; space the pins at the maximum possible intervals.
9. Do not use caulking or hammer working to change the nature of fit, but obtain accurate fits by observing the minimum clearances and interferences prescribed by the drawing.

When checking up the assemblies pay special attention to the mutual arrangement of the working elements of a device with respect to the three mutually perpendicular

planes. The parts and units should be mounted, fitted, and assembled as a complex checking up the position of all the elements relative to the above planes.

In the assembly use is made only of one horizontal plane, that of the surface plate (Fig. 190*a*). This serves as a datum from which the elements are assembled and measured. By moving the indicator parallel to the plane of the surface plate a process is carried out which may be compared to that opposite to projecting: the sizes prescribed by the projection in the drawing are transferred to the part.

When checking up the sizes in the other projection the device is turned over 90° and the position of the part or unit is checked again, now in the plane of the surface plate, i.e., horizontally, according to the sizes of this projection. The sizes of the device in this plane depend upon how accurately it was turned over.

The measuring and checking techniques used in assembly are of much importance. The measurements can be taken by directly contacting the tool upon the work (Fig. 190*b*) or through the aids (Fig. 190*c*). These aids can be in the form of gauge blocks when measuring the distances between the surfaces, or in the form of sized cylindrical shafts when measuring the coordinates between the holes.

The indicators can be used for direct measuring and reading of deviations from the shape of the surface measured, and not the distance between the surface tested and the datum plane. Application of aids allows an extension of the length of the surface measured, hence higher accuracy. This is why the checking of the assemblies is mainly done with the aids.

Flat measuring involves three elements: detecting whether there is any departure from the true geometrical form of the planes; detecting whether there is out-of-parallelism of the planes; measuring the distance between them.

The departure from the true geometrical form, if any, can be detected by applying the straight edge and by the paint method.

The mutual parallelism of the surfaces is checked up by an indicator alone or by an indicator and an aid (a plate).

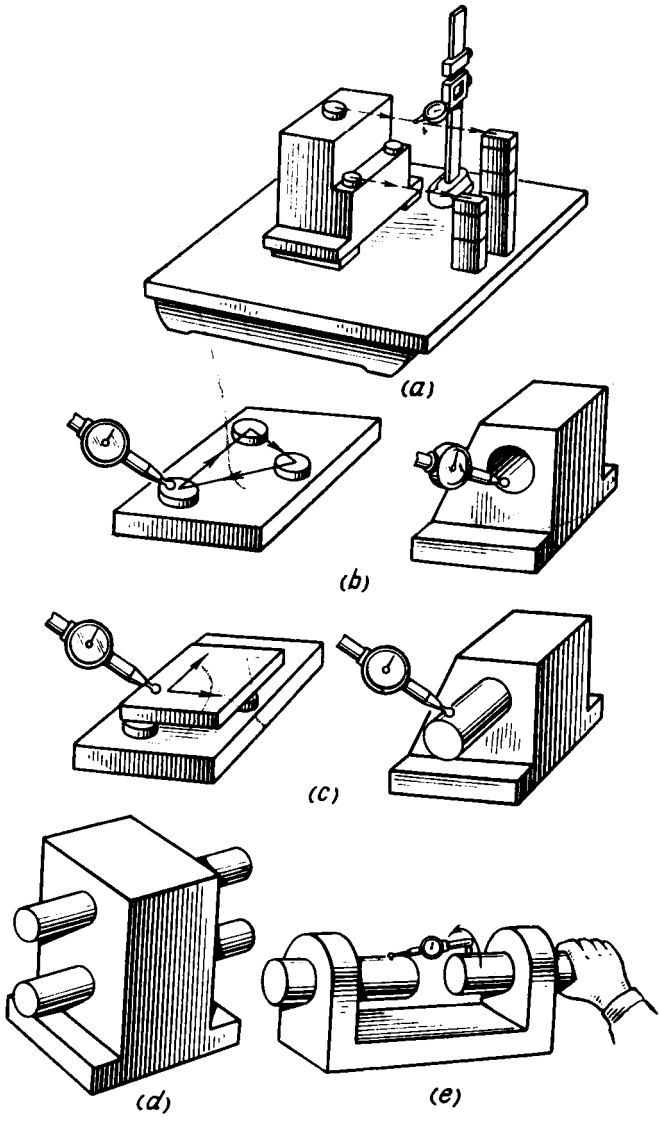


Fig. 190. Methods used for checking up assembled pieces

(*a*) checking up from plate surface; (*b*) taking measurements by directly applying the tool upon the work; (*c*) taking measurements using an aid; (*d*) checking up the distance between hole axes; (*e*) checking up the alignment of holes

The distance between the planes is found using a set of gauge blocks.

The shape and sizes of the holes are tested by indicators, inside calipers, inside caliper gauges.

Non-parallelism of holes and the distances between their axes can be found by the use of shafts entering the holes without clearances and the indicator, the distance being found using a set of gauge blocks and a micrometer (Fig. 190*d*).

Misalignment of holes can be detected with the aid of two shafts: a plain shaft is tight fitted in one hole, and a shaft with an indicator is set in the other so as to allow its manual turning. The half-difference of the readings of the indicators drawn round the plain shaft is the value showing the misalignment of the holes (Fig. 190*e*).

21.10. Repair of Jigs and Fixtures

Repair of machine jigs and fixtures entails high craftsmanship on the part of the repairman since repairing processes cannot be predetermined but should be decided upon at the workplace to suit the faults detected.

The type of repair can differ. The faults being detected are eliminated by machining or bench fitting. It is not infrequent that the repair may involve departure from the drawing dimensions.

To cite one example, the shafts, axles, and pins can be reconditioned by re-grinding them to smaller sizes. Then follows the fitting of the mating parts or their replacement by new ones, or else introducing thin-walled bushings in the existing holes, the bore diameters of the bushings corresponding to the new diameter of the shaft, axle or pin, and the external diameter being adjusted to the tight or press fitting of the bushing which is set in the existing hole of the mated part.

The worn holes are bored for a larger size and a bushing or a new mated part is made (an axle, pin, shaft, etc.).

An alternative method is to make the two worn mating parts and to mount them in the required place.

When the surface is worn, it can be planed and ground, and the clearance formed is compensated for by a spacer.

In drill jigs the most vulnerable are jig bushings. When the bushings depart from their nominal sizes they are replaced or their guide holes are reground for the next nearest size. The external size of the bushing is left intact.

To provide for concentricity of the external and bore diameters, the bushings are ground in the mandrel ("jacket") mounted in the chuck of the internal grinding machine and ground, without resetting, for tight fitting of the bushing.

To recondition heavily worn expensive parts, the damaged areas are hard-faced by electric methods. The extensive areas worn to shallow depth are remedied by metallic coating. Good results can occasionally be enjoyed by building up a coat of chrome by galvanization. In some rare cases the reconditioning of broken parts can be done by arc welding.

Since the majority of jigs and fixtures are to be very precise, their worn or damaged parts are mainly replaced.

The techniques of bench fitting, assembly, and checking up the jigs and fixtures involved in their repair are similar to those used in their manufacture.

The only extra is removal of rust from the used parts before their bench fitting or machining (if the part cannot be reconditioned after hardening).

The rusted parts are washed in kerosene, the rust is removed by steel brushes, abrasives or by scraping. An occasional use can be made of cleaning with a blast of metal shot or of etching in galvanic batches.

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